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CHARACTERIZATION AND TESTING OF OPTICAL FIRE DETECTORS AND IMMUNITY TO FALSE ALARM SOURCES

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ABSTRACT (Continue on reverse if necessary and identify by block number) Optical fire detectors can respond to many sources of UV and IR radiations, including non fire sources. The occurrence of false alarms and "dumps" of fire suppressants in aircraft hangars was substantiated during this study. It was also verified that many potential false alarm sources exist that may affect optical fire detection systems. The feasibility of measuring the spectral characteristics of these potential false alarm sources was established as well as the feasibility of developing qualification test that, when implemented by the detector industry or certified testing entity, will result in the increase of detector reliability against false alarm potentials. Current optical fire detectors perform according to the specification to which they are purchased. Problems with false alarms are thus related to the lack of detailed specifications that need to be provided to industry for future detector procurements. It was concluded that a Phase II effort would result in reducing the potential down-time of fire protection systems, increasing the availability of mission-essential aircraft and increasing mission success survivability.

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EXECUTIVE SUMMARY

The objectives of this study were to determine the feasibility of (1) determining the characteristics of electromagnetic radiation emissions from all sources that may affect optical fire detectors and cause them to false alarm or false activate the fire extinguishant system, and (2) developing qualification test procedures to prove detector immunity to false alarms due to the presence of such sources. The ultimate objective of the program is to increase the reliability of fire detectors. The accomplishment of this objective will help to increase the survivability of mission essential weapon systems, minimize interruptions in aircraft ground operations, and reduce detrimental effects of fire extinguishing agents on the environment, such as atmospheric ozone depletion.

The nature and complexity of operations in aircraft hangars and support facilities and their associated fire threats dictate the need for very fast, effective fire detection and suppression systems. Some fire threats require detection and suppressant activation in only a few seconds. This requires high detector sensitivity thresholds. Increasing the sensitivity of a detector to detect fires also results in the detector becoming more susceptible to responding to nonfire sources that emit radiation in the same wavelengths as fire events. This response to nonfire sources has caused (and still is causing) false alarms and false activations of the extinguishant systems (e.g., Halon 1301, Halon 1211, water, or AFFF foam) at Air Force bases on many occasions.

Optical fire detectors operate on the basic principle of detecting ultraviolet and/or infrared emissions from hydrocarbon fires. Unfortunately, there are other sources of such radiations that are not fire-associated, but nevertheless cause a detector to false alarm or false activate the suppressant system. Such false alarms and releases of suppressant can have major impact upon military operations, result in financial loss, cause environmental problems such as atmospheric ozone depletion, and remove the fire protection system from operational status during refurbishment and/or maintenance, therefore leaving mission-essential aircraft unprotected for some period of time. In some instances where the frequency of occurrence of false alarms is high, the entire fire detection system is disconnected awaiting replacement, repair, or some other solution. It is important, therefore, that fire detectors and their electronic controllers be immune to false alarm sources and provide fire protection at all times, not just some of the time.

This study consisted of reviews of past false alarm events and their possible causes at selected Air Force bases in the United States, Europe and Pacific. It also included identification and description of possible false alarm sources that may exist in or near aircraft hangars, hush houses, fueling docks, maintenance facilities, and ramps. A determination was made of where field measurements could be made of the emission characteristics of these sources, including aircraft-associated emissions. Also, a determination was made of the equipments required for field measurements and qualification test facility measurements.

Data was obtained from the Air Force Inspection and Safety Center and the Navy Safety Center on reported fire events and false alarm events in aircraft-related facilities/hangars over the past few years. About half of the false alarm events were caused by mechanical and environmental problems and the other half by lightning, light sources, welding, aircraft engine exhaust emissions, and other phenomena.

Information was also obtained from fire detector suppliers regarding false alarm problems. On-site inspections were made of fire protection facilities at various Air Force bases and discussions held with Fire Department, Civil Engineering, Maintenance, and Aircraft Ground Crew personnel on subjects of false alarms and fire events.

It was found that many false alarm events have occurred and that in some instances the fire detection system was (and still is) disconnected. It was also found that thermal gradient/rate-of-rise detectors had false alarm problems, mostly due to low threshold temperature settings, low ceiling mounting location, and close proximity to hot aircraft engine exhaust. It was verified that a problem does exist with optical fire and heat detector false alarms and that they are predominantly caused by radiative emissions from nonfire sources as well as from environmental conditions such as shock, vibration, water seepage, and soiled detector windows.

False alarm sources were separated into discrete and complex categories. The former category consisted of those items that could easily be included in a qualification testing facility. This category consisted of many types of lights that are associated with aircraft, facilities, ground equipments, tools, vehicles and utilities. Examples include Movie Lamps, Xenon Lamps, Mercury Vapor Lamps, Aircraft IFR and Landing Lights, Fluorescent Lamps, Sodium Vapor Lamps, and Electronic Flash Lamps.

The complex category of false alarm sources consisted of such items as cigarettes, matches, lighters, electric arc, acetylene welder, arc welder, rifle flash, sunlight, engine wet-starts, aircraft engines, hot manifolds on vehicles and support equipments, and afterburner flame. Most of these types of sources cannot be easily adapted to the laboratory and need to be simulated.

It was assumed that costs would be minimized if all the field measurements of the spectral characteristics of false alarm sources could be made at one location over a short time period. A survey was therefore made to determine which Air Force bases had most, if not all, false alarm items, including appropriate facilities and a broad contingent of aircraft (e.g., F-15, F-16, F-111, A-10, B-1, B-2, wide-body etc.) that could possibly be made available. Edwards Air Force Base near Lancaster, California, was determined to be an ideal location for the field measurements program.

A field measurements data acquisition plan was developed, along with a plan to develop qualification test procedures to prove detector immunity. Equipments, materials, supplies and facilities were identified for these purposes.

The study concluded that the identified false alarm problems can be solved if detector suppliers are required to meet more stringent qualification and performance specifications. At present, detector suppliers provide what they are asked to provide by the procuring agency. The performance, reliability, and qualification specifications must therefore be expanded and upgraded to include false alarm immunity requirements as well as more stringent environmental requirements. This is the responsibility of the Air Force, although industry's participation in developing these upgraded specifications and procedures would greatly accelerate the process of making available more reliable fire detectors and electronics.

It was also concluded that all the technical requirements necessary to prove feasibility of conducting a Phase II effort and in achieving the ultimate objectives of the overall program were satisfied during the study.

The results of the study are useful to the Air Force fire detector users, military procurement agencies, and the detector industry as a whole. The military user/buyer will be able to prepare more definitive performance, reliability, military standard conformance, and quality specifications for purchase descriptions. A better understanding of equipments and operations that may cause false alarms will also help the Air Force to impose restrictions and guidelines for hangar operations and fire protection system configuration.

The detector industry will also benefit in that it will have a better understanding of the causes of false alarms and the nature and properties of the false alarm sources. Such information will help to guide R&D in new detector design and qualification testing, leading to better products, more applications, and an expanded market.

It was the recommendation of the study that a Phase II effort be pursued with diligence by the Air Force and that it be given high priority because of the resulting benefits of increased aircraft mission success, cost savings, reduction of environmental effects, and increased survivability of military operations and mission-essential weapon systems.

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PREFACE

This final report was prepared by Donmar Limited, 901 Dover Drive, Suite 120, Newport Beach, California 92660, under SBIR Contract #F0835-89-C-0380, with Headquarters Air Force Civil Engineering Support Agency, Civil Engineering Laboratory (HQ AFCESA/RA), Tyndall AFB, Florida 32403-6001, as the sponsor.

The period of performance for this contract extended from July 28, 1989, through December 28, 1989. AFCESA/RACF project officer is Chuck Risinger.

This technical report was submitted as part of the Small Business innovative Research (SBIR) Program and has been published according to SBIR Directives in the format in which it was submitted.

The author would like to acknowledge the assistance provided by the Fire Departments and Civil Engineering Departments at Beale AFB, Edwards AFB, Hickam AFB, McClellan AFB, AFCESA/DF, Tyndall AFB, USAFE Ramstein, Germany and Norton AFB; and the Air Force Inspection and Safety Center, Norton AFB; and the Fire Protection Division, PACAF Headquarters, Hickam AFB.

This report is releasable to the National Technical Information Service (NTIS) and will be available to the general public and foreign nationals.

This technical report has been reviewed and is approved for publication.

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GLOSSARY OF TERMS

TERM	DEFINITION
AF	AIR FORCE
AB	AFTERBURNER
AFB	AIR FORCE BASE
AFESC	AIR FORCE ENGINEERING SERVICES CENTER
AFFF	TYPE OF FOAM FIRE SUPPRESSANT
AGE	AIRCRAFT GROUND EQUIPMENT
AFISC	AIR FORCE INSPECTION AND SAFETY CENTER
CGB	CENTRAL GEAR BOX
CONUS	CONTINENTAL UNITED STATES
EM	ELECTROMAGNETIC
EMI	ELECTROMAGNETIC INTERFERRENCE/EMISSIONS
FM	FACTORY MUTUAL
FPS	FIRE PROTECTION SYSTEM
GFE	GOVERNMENT FURNISHED EQUIPMENT
GSA	GOVERNMENT SERVICES ADMINISTRATION
GSE	GROUND SUPPORT EQUIPMENTS
HALON	CHLOROFLOUROCARBON FIRE SUPPRESSANT
HAS	HARDENED AIRCRAFT SHELTER
HUSH HOUSE	FACILITY TO TEST AIRCRAFT ENGINES
IFR	IN-FLIGHT RE-FUELING
IR	INFRARED RADIATION
JAMMER	EITHER A WEAPONS LOADER OR DEVICE TO DISRUPT ELECTROMAGNETIC EMISSIONS
JFS	JET FUEL STARTER
JP4	TYPE OF JET FUEL
MIL-STD	MILITARY STANDARD
MTBF	MEAN-TIME-BETWEEN-FAILURES
NACELLE	ENGINE COMPARTMENT AREA
NDI	NON-DESTRUCTIVE INVESTIGATIVE ITEM
PACAF	PACIFIC AIR FORCE
QA	QUALITY ASSURANCE
SBIR	SMALL BUSINESS INNOVATIVE RESEARCH
TAB V	TYPE OF HARDENED AIRCRAFT SHELTER
UL	UNDERWRITER'S LABORATORY
USAFE	US AIR FORCE EUROPE
UV	ULTRAVIOLET RADIATION

SECTION I

INTRODUCTION

A. OBJECTIVES

The overall objectives of this research were to determine the characteristics of radiative emissions from possible false alarm sources; to develop methods to simulate such sources, if required, in laboratory test facilities; and to develop qualification test procedures which will help industry to develop and supply detectors that are immune to false alarm sources. A major objective of the SBIR Program is that some economic benefit result from the overall effort. This is discussed below in Section I-C.

This Phase I contract effort was directed at establishing the feasibility of accomplishing the overall program objectives stated above. To establish this feasibility a number of subjects had be to reviewed, including (1) background information on past false alarm events; (2) analysis of possible false alarm sources; (3) the locations where measurements could be made on the these sources; (4) the laboratory and field optical measurement equipments that would be necessary; and (5) the method and facility description necessary to develop the simulations and qualification test procedures.

B. BACKGROUND

The nature and complexity of operations in aircraft hangars and support facilities present a number of potential fire threats. These fire threats range from small floor fires that can be easily extinguished with hand-held extinguishers, to major running fuel fires consisting of many gallons of jet fuel that must be rapidly extinguished in order to protect aircraft, facilities, weapons, and personnel. Other fire threats may be associated with the aircraft itself, such as those resulting from problems with engine starts. Three dimensional fire events that involve the aircraft, as well as the floor, pose unique problems in fire detection and suppression.

Regardless of the type of fire event, it must be extinguished and/or controlled to minimize damage and disruption of military operations. To do this, a fire detection system must act fast to identify the fire event and to activate alarms and release fire suppressants. The current AF requirement for optical fire detector response to a JP-4 fire in a hangar is to identify a fire of at least 10 feet x 10 feet size at a distance of 150 feet within 5 seconds (Reference 1).

Other AF published information on performance of hangar fire protection systems quotes a time of 90-120 seconds from fire start to 90 percent fire control (Reference 2). During the Hardened Aircraft Shelter Fire Protection System Development and Test Program, it was concluded that the fire protection system specification should be to detect and <u>extinguish</u> any fire of 16 ft^2 or more at any time and at any location in the hangar within 15 seconds after fire start, and typically less than 10 seconds after fire start (Reference 3). The recent B-2 Hangar Fire Detection System Specification released by the US Army Corps of Engineers on behalf of the USAF, required detector response to a 12-16 ft^2 fire anywhere in the hangar within 5 seconds (Reference 4). The need for fast, reliable fire detection is obvious when mission-essential aircraft and weapon systems are involved.

Optical fire detectors that operate in the ultraviolet, infrared, and visible wavelength regions are sensitive to hydrocarbon fire emissions and can be adjusted in their sensitivities to detect fires of different sizes, located over a large range of distances, within a range of response times. The more sensitive a detector is the faster it can react to the specified minimum size, maximum distance fire. However, the greater the sensitivity of a detector, the greater the probability of response to nonfire, "false alarm" sources that also emit in the UV and IR regions. Tradeoffs must therefore be made between threshold sensitivities, time to identify a fire and reliability against false alarms.

The need for reliable fire detection is the major concern. It is not cost-effective to install fire detection systems, then have to disconnect them because they respond to nonfire sources and cause false alarms and false dumps of the suppressant. It is also self-defeating to turn off a fire detection system in a hangar when certain activities or equipments present may "fool" a detector into believing that a fire exists. A fire protection system must protect the aircraft and facilities at all times, not just some of the time.

As discussed later, false alarms do occur and are associated with various UV, IR, visible, EM and ionizing radiation emitting sources and environmental factors such as vibration, shock and water leakage.

The problem then is how to assure reliable fire detection and reliable performance to discriminate against possible false alarm sources.

It should be clarified that industry provides optical flame and heat detectors that perform according to the purchase specifications required by the buying organization, whether it be the Army Corps of Engineers acting for the AF, a general contractor, a construction contractor or the AF itself. If false alarms occur, the reasons may be attributed to one or more of the following: (1) the detectors do not meet specification or may have reached their lifetime or MTBF; (2) the specification for the purchase of the detectors was not sufficiently detailed to cover all the false alarm sources that may be present, the environmental extremes to which the detectors and logic controller may be exposed, and the test procedures required to prove reliability; and (3) that the characteristics of optical radiation emitting equipments and sources that exist in the field-of-views of the detectors were not known or adequately defined.

If specific characteristics were known for all possible sources of radiations and environmental factors that can confuse an optical fire detector, more detailed specifications could be written and more detailed qualification test procedures could be requested of industry. The result would be more reliable fire protection.

Examples of radiations that can confuse an optical fire detector include natural phenomena such as sunlight and lightning; electromagnetic interference (EMI) from aircraft radar and communications systems, hand-held radios, and NDI items; IR emissions from aircraft engines and on-board components; and UV, IR and X-ray emissions from aircraft ground equipment (AGE) such as light sources, power sources, front-end loaders, jammers, heaters, air conditioners, steam cleaners, non-destructive investigative items, lamps, vehicles, and many other items. Sources that are extraneous to aircraft facilities such as welding torches, area illumination lighting, discharges/arcing of transformers on telephone poles, and aircraft afterburners in the distance can also be detected by optical fire detectors unless they are designed and qualified to "ignore" such non fire emissions.

The costs, operational impacts and environmental effects may be large when some suppressants are accidentally discharged inside a hangar and over mission essential aircraft. Not only cost of the suppressant is a factor, but in addition are the related costs of having to disassemble and clean engines and other systems on the aircraft should certain types of dry chemical, powder or other suppressants penetrate into engines and internal electronic and mechanical systems. Downtime is especially expensive for operational aircraft that may be involved in a fast integrated combat turn situation. Downtime of fire protection systems due to refurbishment and/or repair/ replacement is also a factor that can increase the vulnerability of weapons systems to fire events. If halon was used as the suppressant and the engines were operating during the dump, they would be extinguished and difficult to start until the halon concentration decreased. Also, the release of halon into the atmosphere is of major concern today. False dumps of suppressants, therefore, can seriously affect aircraft operations, reduce mission survivability and have deleterious environmental effects. Immunity of optical fire detector systems to possible false alarm sources, whatever they may be, will reduce the likelihood of false dumps and, therefore, minimize the problems referred to above.

Some AF bases with installed optical flame and heat detectors have had false alarm and false suppressant dump problems. The occurrence of such accidents at various locations over the past few years was verified by the following: (1) during visits with Fire Department, Maintenance and Engineering personnel at Beale AFB, Edwards AFB, McClellan AFB, Norton AFB, Hickham AFB, USAFE bases and PACAF Headquarters; (2) review of information on AF accident reports obtained through the Naval Safety Center and the AF Safety and Inspection Center, and (3) through discussions with optical fire detector companies.

All the blame for false activations and alarms cannot be attributed solely to the response of optical fire detectors to emissions from nonfire sources. Some problems have occurred because of faulty installations, environmental effects on both detectors and controllers, and lack of detailed performance specifications. As will be demonstrated herein, detailed purchase descriptions that include high-performance criteria covering environments, reliability, mean-time-between-failures, quality assurance, and proof of performance via qualification tests would help to reduce these problems. High and low temperature extremes, water immersion, shock, vibration from aircraft engines, fungus, humidity, salt and electromagnetic emissions all contribute to increasing the susceptibility of detectors and electronics to false alarm/dump and to fail.

C. POTENTIAL COMMERCIAL BENEFITS

Fire detector manufacturers can be separated into two groups. One group includes those companies that produce military qualified detectors and electronics that meet stringent military specifications and standards. These companies employ DOD quality assurance procedures such as Mil-Std-9858A and have significant facilities and equipments required for qualification testing. The fire detectors supplied by these companies are typically used for crew and engine bay fire protection on military fighting vehicles and dry bay, fuel bay and engine compartment fire protection on military aircraft and helicopters. Over 10,000 of these military standard-designed and tested detectors have been integrated into military weapons systems. None of these devices require UL or FM approvals, as the military standard requirements are more stringent and there is no need to satisfy local construction/facility fire codes. These detectors serve the sole purpose of protecting the weapon system and personnel. They operate in dual IR or single UV wavelengths and have response times of tens of milliseconds. In some cases they are designed to discriminate hydrocarbon fires from "hot" penetrating and incendiary munitions.

Companies in the second group primarily market their fire, heat and smoke detectors to commercial and industrial buyers where the major application is "building/ facility" fire protection. These products, in general, are not required to conform to stringent military specifications and standards, high MTBFs and reliabilities, or performance qualification testing typically required of internal aircraft and weapon system fire detectors. These are the detectors that are presently being purchased to protect such aircraft as the B-1, B-2, F-15, F-16, F-111 and other Air Force operational aircraft, including their hangars and maintenance docks. They are usually procured as part of the Military Construction Procurement (MCP) "building" fire protection requirements. Instead of being governed by military design and qualification standards, they are designed to conform to local and other construction codes and require UL and/or FM certification. The AF requirements for the performance of these detectors are included in AFR-88-15, which basically requires a detector to identify a 10-foot X 10-foot pan fire at a distance of 100 feet within 5 seconds (Reference 1). The optical fire detectors supplied by this group of companies operate in UV/IR, IR/IR, IR and UV bands, have field-of-views of 80- or more degrees and respond to a fire in seconds.

The major differences between the optical fire detectors produced by the two groups of companies are the quality of components, performance requirements under various environmental conditions, levels of quality assurance standards and degree of qualification testing imposed during the manufacturing process. The use of military standard components versus the use of commercial components is a difference that is reflected in the product's MTBF, series electronic reliability and mission success reliability. It also affects the logistic life cycle costs.

The procurement procedures to purchase the above two products are different. In the former case a request for proposal (RFP) is released to potential suppliers through the weapon system manufacturer or the military system procurement office (SPO). The RFP includes detailed specifications, testing and performance requirements. The competing companies must submit technical proposals and verify that they conform to all design, test, reliability, quality and performance requirements. Proof that QA procedures such as Mil-Std-9858A are in effect must also be provided in the proposal. Installation, wiring, connectors, parts quality and other electrical/mechanical items are specified according to military standards.

In the latter case the fire detection and suppression systems are usually included as part of the facility protection requirement and are procured through construction contractors via the Army Corps of Engineers where minimum price is a major factor (but not the sole factor) in selecting the winner. Selection of the fire detection system is not made by the Air Force (or SPO), but rather by the low bidder/winner of either the construction contract or fire protection system and installation contract. The entire job is bid as one cost package and the bidder has the latitude to select whatever fire detection system that falls within his pricing motives as long as the basic performance requirements and specifications are met. If certification (UL or FM) can be cited that the detectors conform to basic fire response requirements, the detector is basically qualified for purchase.

Commercial/industrial detectors can be purchased from an "approved" GSA Federal Supply Schedule at a pre-negotiated price. No military standard detectors are on this list. An Air Force base can purchase detectors on this approved schedule directly from the manufacturer without formal requirements for a proposal or price quote. The criteria employed in getting a detector listed on this schedule does not include specifications of reliability for false alarm immunity discussed herein. Such a requirement may help in the future to reduce the occurrence of false alarm events.

An Air Force objective of this SBIR Program is to increase the reliability of commercial/industrial fire detectors for military hangar applications by developing appropriate false alarm immunity qualification test procedures that can be easily performed by detector manufacturers and independent certified testing companies.

The above test procedures and specifications, if adhered to by industry, will result in detectors that have increased immunity to false alarm sources and provide the upgrade in reliability desired by the AF. Suppliers will also have products that are availing in other high-tech commercial applications. As more high-tech, military application products are sold, the lower will be the cost for standard industrial applications.

The SBIR guidelines require that a commercial benefit result after the Phase II effort. The potential commercial benefits resulting from this SBIR program include the following: (1) increased detector reliability could result in a greater product demand, especially in the military and high-tech user sectors; (2) as the quantity of products sold increases the production costs would decrease and the price saving may be passed along to the buyer (also, as the prices decrease the market-of-interest would expand, thus increasing sales potential); (3) industry would have the opportunity during the SBIR Phase II development effort to participate, thus reducing initial costs for start-up R&D to meet the false alarm specifications; (4) the results of an SBIR Phase II effort could also be integrated into the design and development of other, new technology fire and intrusion detectors, such as machine/computer vision; (5) industry may be able to provide reliable fire detectors for special purpose applications such as B-2 Hangars and hypergolic fuel fires, thus expanding market sales volume; (6) there may be direct application to AF space systems (USAF SPACECOM) and related activities; (7) detector reliabilities may be realized for such applications as Hardened Aircraft Shelters at USAFE, PACAF and NATO bases, Flow-Through-Alert-Hangars at various AF bases, and B-2 and other large hangars; (8) the US detector industry may have a better product and may be able to compete more effectively in the international marketplace; and (9) as the detector's performance increases so would the applications.

D. SCOPE/APPROACH

Fire protection system requirements and false alarm source problems were reviewed. Additional information was obtained by visiting the Air Force bases stated in the Preface Section and meeting with Fire, Civil Engineering and Aircraft Maintenance Department personnel. More detailed information, was requested via a message from the AFESC Director of Fire Protection to all base Fire Chiefs. Responses to this request were not received in time to be included in the Phase I study effort, but would be available at the beginning of a Phase II effort.

Data on recent reported false alarm/false dump events that resulted in some financial impact were obtained from the Navy Safety Center. These data covered mishaps in hangars during 1987 and 1988. These specific data are not releasable in this report but can be obtained through appropriate government channels. The occurrence of other non reported events were verified in discussions with Air Force base Fire Department, Aircraft Operations, Maintenance, Engineering, and Management personnel, and in reviews of ledgers/notebooks during on-site visits.

Detector companies provided information on some recent false alarm events in hangars.

Data were also obtained from the Air Force Inspection and Safety Center on aircraft-related hangar fire events. These events were documented in summary reports of Jet Fuel Starter(JFS)-associated fire events between 1978 and 1988 involving F-15 and F-16 aircraft, Cart Starter-associated fires between 1976 and 1988 involving F-4 aircraft, and ground mishap fires in hangars from all causes between 1979 and 1988. These data are also not releasable in this report but can be obtained for government use through appropriate channels.

Some preliminary information on spectral emissions was obtained from manufacturers of light sources and Non Destructive Inspection (NDI) items. These data were analyzed for UV spectral emission characteristics.

The detector industry was informed of the SBIR study objectives via a press release and through telephone conversations during the course of the study.

As a requirement to determine feasibility of conducting a Phase II effort, discussions were held with Air Force personnel at the locations stated in the Preface Section regarding the availability of specific "false alarm" sources and the possibility of using Air Base facilities, aircraft and equipment to conduct field measurements of radiative emissions.

The physical and performance characteristics of the laboratory equipment, field measurement equipment, and data recording equipment required to conduct the Phase II field and lab measurements were identified. A detailed analysis should be made at the beginning of the Phase II effort to locate and acquire the most cost effective equipments outlined in Section III-E.

The recommendations on where to make field measurements and where to locate a qualification test laboratory were primarily based on cost considerations. For example, Edwards AFB has available almost every type of aircraft-of-interest, including the B-2, and has most, if not all, of the facilities, AGE, NDI equipment/facility and false alarm sources required to the conduct of the Phase II effort. If travel is necessary to obtain such measurements in more than one geographical region there would be added cost impacts due to additional labor, transportation, packing, shipping, equipment calibration, communications, lodging/per diem and other items.

Repeat visits and rescheduled measurements at the selected Air Force base(s) will probably be required. Because the equipments necessary for these measurements would be the same as those used in the qualification test procedures lab, it would be prudent and cost-effective to give priority to locating the qualification test lab within the geographical region where the field measurements would be made. This is especially true for the aircraft-associated measurements because the availability of specific aircraft may be difficult to schedule in advance, thus requiring response at short notice.

SECTION II

REQUIREMENTS OVERVIEW

The requirement to characterize optical fire detector false alarm sources was previously determined by the AFESC and formed the basis of the SBIR program description/announcement.

The Phase I effort was directed explicitly at proving feasibility of conducting the Phase II effort and accomplishing the goals of the overall program as so specified in the SBIR AF89-063 published description. In order to prove feasibility, it was assumed that a number of technical and administrative/management requirements had to be satisfied. This section specifies the requirements addressed in this contractual effort.

A. TECHNICAL REQUIREMENTS

The technical requirements addressed in this effort are as follows:

1. Review of sources that may emit radiations that can possibly cause false alarms.

2. Determination of how and where the spectral emissions from such sources can be measured and characterized.

3. Substantiation that such sources identified above could be made available and/or obtainable for measurement purposes.

4. Determination of equipment needed to make the above measurements.

5. Development of an effective field testing program approach.

6. Determination of the laboratory requirements and approach to develop simulations and to develop qualification test procedures to demonstrate immunity of both detectors and detection systems to discrete and complex false alarm sources specified herein.

B. MANAGEMENT AND ADMINISTRATIVE REQUIREMENTS

These requirements included the following:

1. Determination that the program can be accomplished within time and cost guidelines consistent with a Phase II program effort as set forth in the DOD SBIR 1989 Announcement.

2. Determination that arrangements and coordination can be accomplished with Air Force bases for the field effort.

SECTION III

TECHNICAL REQUIREMENTS AND ACCOMPLISHMENTS

This section addresses the technical requirements stated in Section II and what accomplishments were made during the Phase I contract to prove feasibility of meeting the overall program objectives of increasing the reliability of optical fire detectors against possible false alarm sources.

A. OPTICAL FIRE DETECTORS

Hydrocarbon fires emit radiation in the wavelength range of about 180 nanometers to about 5 micrometers (see Figures 1, 2 and 3). This range includes the ultraviolet, visible and infrared regions of the electromagnetic spectrum.

Figure 1 shows the UV emissions from JP-4 fuel burning at sea level. The figure is separated into three parts that are extensions from left to right. The plot on the left shows the spectral radiant intensity of 200-240 nanometer UV emission over the range of about zero to 8×10^{-9} Watts per nanometer per steradian. The middle plot is a continuation of the left plot where the ordinate extends from 9×10^{-9}- to 8×10^{-8}-Watts per nanometer per steradian over the wavelength range of 240 through 280 nanometers. The plot at the right is a continuation of the middle plot and shows a continuing rise in energy emission from 280 nanometers through the peak intensity level of 4×10^{-7} Watts per nanometer per steradian at 310 nanometers. The emission curve then decreases at a fast rate at wavelengths greater than 310 nanometers.

Figure 2 shows the broad-band emissions in the visible and near-infrared regions for JP-4 burning at various atmospheric pressures. It is apparent that most of the near infrared energy is contained in the wavelength range of about 1.2 through 2.0 micrometers.

Figure 3 shows an extension of Figure 2 into the far-infrared region. Note the predominant emission peak at 4.3 micrometers.

In selecting the specific wavelength bands to detect fires it is important to determine what regions also contain high intensities of background radiation, such as from the sun, that could cause "false alarms." In the infrared region, hydrocarbon fires emit strongly in the 4.1- to 4.6-micrometer range, while very little solar radiation in this region penetrates the atmosphere due to carbon dioxide absorption (see Figure 4). The narrow emission band located at 4.3 micrometers is usually chosen as the center of the infrared detection band because it is the predominant emission line from CO_2 in the flame front.

In the ultraviolet region, very little solar radiation in the wavelength range of 180- to 220-micrometers penetrates the atmosphere due to water absorption (see Figure 4). In the range of 240- to about 290-nanometers the atmosphere is relatively transparent, thus having little effect on UV transmission. Hydrocarbon fires emit UV radiation in this region and are therefore easily seen in the UV because little background UV "noise" exists.

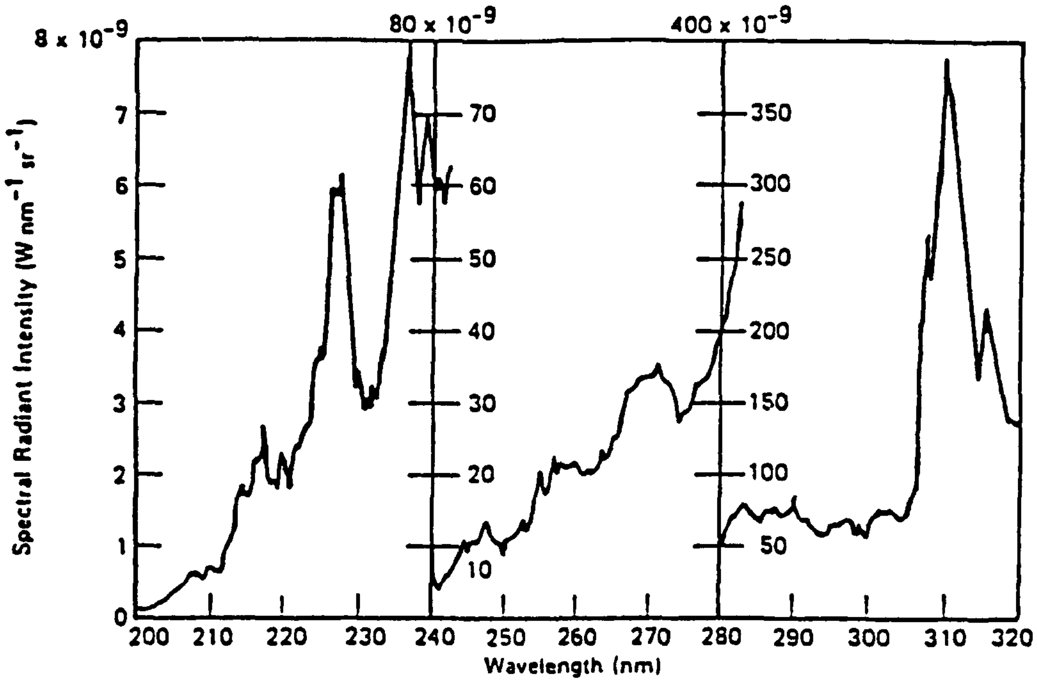

Figure 1. Spectral Radiant Intensity of JP-4 Burning at Sea Level (200-320 nm) (Reference 5)

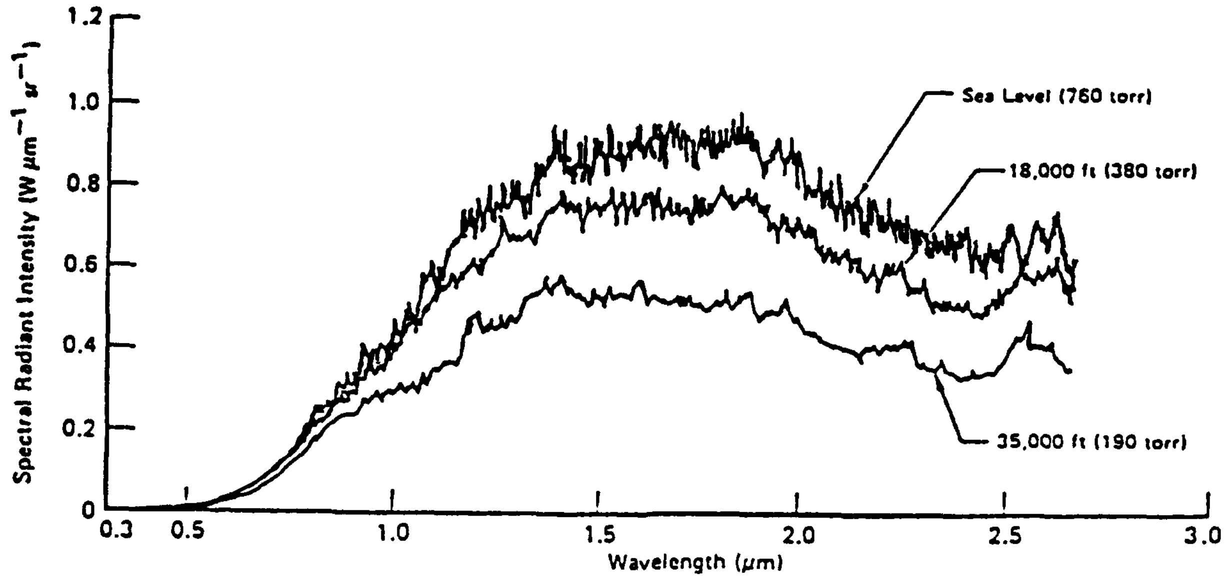

Figure 2. Visible and Near Infrared Emissions from JP-4 Burning at Various Altitudes (Reference 5)

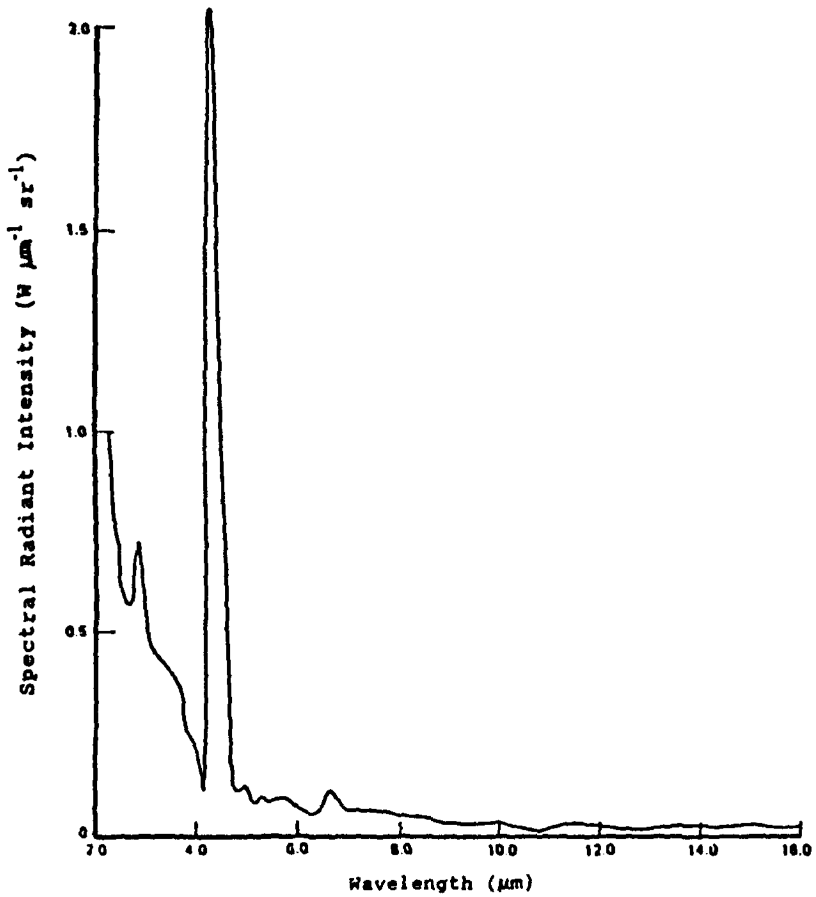

Figure 3. Far Infrared Emissions from JP-4 Burning at Sea Level (Reference 5)

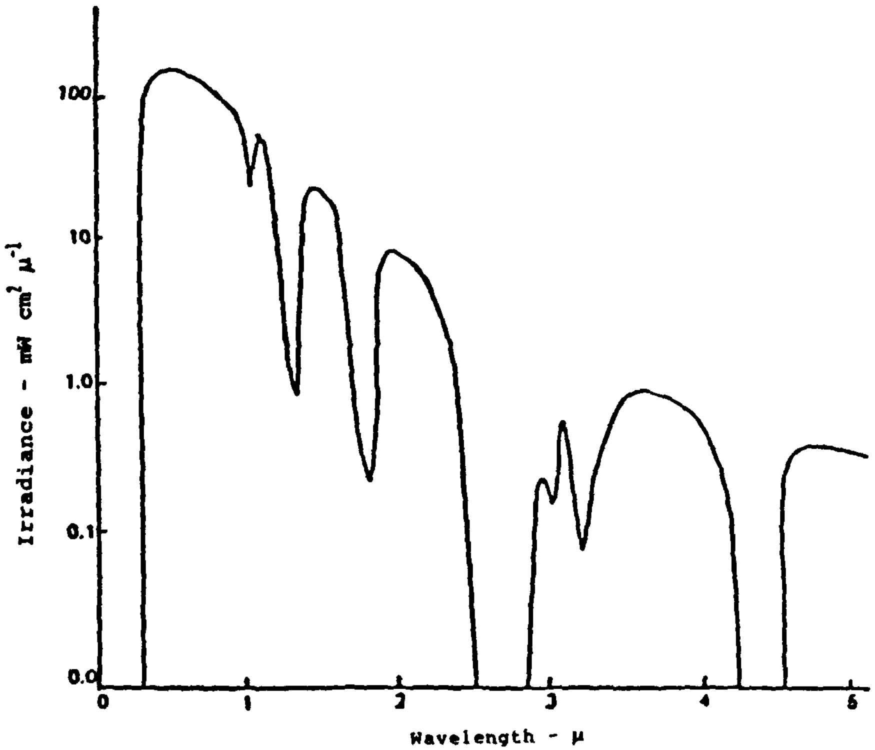

Figure 4. Spectral Irradiance vs. Wavelength for Solar Radiation

To reduce solar radiation influence on the performance of an optical fire detector, UV and IR measurement bands should be chosen where the solar background radiation is minimal and where the atmosphere has little effect on the transmittance as shown in Figure 4. This is why most detectors operate in the above bands, typically centered at or near 240- to 290-nanometers and 4300 nanometers respectively.

Most detectors today consist of single or multiple channels of UV and/or IR sensors whose outputs are processed in various ways to reach an "alarm" or "fire" decision. Some detectors also utilize optical flame flicker as another data input to provide more specificity of a hydrocarbon fire (typical flicker between 5 and 30 Hz). The technology of UV and IR sensing is well established and offers a number of benefits such as self-testing through the use of built-in emitters that are automatically activated at some preset interval of time.

The more detailed spectral emission data obtained by a detector, the more specific determination of the physical nature of the radiation emitting source can be. In other words, if the exact spectral emission characteristics of the many types of fire and false alarm sources were known and if a detector could measure such high-resolution spectral emissions and compare them against a library of stored spectral data, a very accurate determination of the nature of the source would be possible. This technique, used in laboratory spectroscopy would be beneficial in fire detector signal processing but it requires a very large stored data base and very large amounts of high-resolution spectral measurements over a broad spectrum from UV through the IR. The use of machine vision technology may provide this specificity without the need for large amounts of high-resolution spectral data input.

Today's detectors do not measure discrete, narrow line emissions and are not specific in discriminating between the nature of radiation sources they detect. For this reason measurement of very fine, high-resolution spectral emissions of each and every possible false alarm source may not be necessary, although narrow-band emission measurements in the UV may be helpful in quantifying fire detector responses. The IR emissions from "hot" bodies are very broad-band, black body-type of emissions with little predominant spectral emissions for hydrocarbon fires except near 3.0- and 4.3-micrometers (Figures 2 and 3).

The following discussions include the various types of radiation emitting sources to which optical fire detector's must be immune; results of some first-hand surveys into the false alarm problem; field measurement requirements; simulation approaches; and qualification test procedures development.

B. FIRE THREATS AND FIRE EVENTS

There are several potential fire threats in an aircraft hangar environment. In the extreme case, a catastrophic event may occur in less than one minute after a major fuel spill fire. Other fire events may also result in significant damage to aircraft if not extinguished rapidly. Burn-off times for pyrotechnic items may be of the order of minutes or so. Regardless of the times of various stages of damage resulting from internal aircraft and floor hydrocarbon fires, there is normally some cost impact. There is also the danger of personnel injuries and the impact on a military operation to carry-out missions. Reduction in vulnerability and increased survivability of aircraft and military operations is an objective of the DOD.

Fires may result from a jet fuel spill on the floor, drop of a wing tank, backfire/wet-start of an engine, failure or backfire of a Jet Fuel Starter (JFS), breakage of a fuel or hydraulic line, overflow of fuel from wing vents impinging a hot exhaust pipe on an Aircraft Ground Equipment (AGE) item, or a spark from a dropped tool or electric arc on a pool of fuel on the floor. Regardless of the nature of the fire, all require rapid identification and extinguishment. Optical fire detectors provide the necessary fast reaction times to meet these fire threats.

As an example of a major fire threat, a fuel truck inside a hangar backed into the hangar doors, split open, and dropped hundreds of gallons of JP-4 on the floor. There were no major ignition sources present at the time (such as engines running, etc.) and no fire resulted. However, this could have been a catastrophic event requiring very fast fire detector response and suppressant release.

According to data provided by the AF Inspection and Safety Center (this data is only available for appropriate government use), about 80 fire events were reported in the past 10 years in Air Force aircraft hangars and hush houses and on trim pads and ramps. Of these 80 events, about 60 were inside hangars/facilities. About 20 of these events were associated with internal aircraft fires, 20 due to maintenance mistakes and electrical failures and 20 due to AGE item fires. Approximately 35 of these events required the Fire Department's assistance to extinguish the fire. The others were extinguished with hand-held extinguishers. The cost impact of these 80 fires was reported to be \$8.4 million damage to aircraft and AGE and \$48 million hangar loss (one event). None of the reports of these events referenced the existence of optical fire detectors or automatic/manual fire suppression systems in any hangar.

In addition to the above reported fires, there were other hangar fires that were not reported because no significant financial loss was incurred in the events, such as Class C (at least \$10,000 loss). The occurrence of such events was verified during visits with AF personnel at the locations stated in the Preface Section.

There have been other fires that were directly associated with Jet Fuel Starters, cartridge starts, and engine problems. Data obtained from the Air Force Inspection and Safety Center indicates that 94 such events were reported over the past 10 years that involved F-4, F-15, and F-16 aircraft only (data related to other aircraft was not requested). Although most of these reported events occurred on the ramp, they could have just as easily occurred in hangars if the hangar operations procedures permitted such aircraft engine operations (e.g., "hot integrated combat turns"). Other, smaller fire events occurred in hangars but were not reported because they either did not satisfy the "minimum financial loss" criteria or for some other reason. The occurrence of these smaller, non reported events was verified during discussions with aircraft maintenance personnel at various AF bases. Their frequency-of-occurrence is presumably low. These JFS-type of events can constitute both a fire threat as well as a potential "nuisance" alarm source that could result in a full suppressant dump when only a hand-held extinguisher is needed.

C. IDENTIFICATION OF POSSIBLE SOURCES OF RADIATION(S) THAT COULD CAUSE FALSE ALARMS/ACTIVATIONS - TECHNICAL REQUIREMENT 1

In addition to hydrocarbon flame fires, there exist other sources of radiation emissions in and near aircraft facilities that may satisfy an optical fire detector's threshold requirements for the presence of a fire. Some of the false alarms and accidental dumps of suppressant that have occurred in aircraft hangars and facilities were the result of the presence of one or more non fire sources in the field-of-view of the detectors. For example some recent false alarms that were reported by AF base personnel during the Phase I effort were due to one or more sources outside the hangars such as AGE, welding, lightning, lights and transformer arcing that could be seen by the detectors inside hangar units.

Also, discussions with Air Force personnel and industry representatives revealed the occurrence of other false alarms due to engine starts, X-rays and various light sources.

Environmental factors also contributed to some of the accidental alarms and activations that were communicated by AF base personnel during the course of the Phase I study. These included shock, aircraft engine-induced vibration (and failure) of electronic components and water intrusion into detectors and controllers.

There are various types of radiation-emitting sources associated with aircraft, hangars, facilities, extraneous activities, ground support equipment, tools and test equipment. Natural phenomena such as lightning and solar radiation have been historical problems with UV fire detectors. Some items in these categories do not have direct emissions in wavelength regions in which optical fire detectors operate but under certain conditions can directly influence the performance of a detector or the electronics circuitry. For example, a mercury vapor lamp has a distinct UV line emission, but the glass lens that covers the bulb is supposed to absorb the UV. If the lens is cracked or broken, UV radiation would escape. Figures 5-17 show various AGE items that have emissions in the UV and/or IR.

Another example is that non destructive testing devices such as X-ray machines (see Figure 18) are used to identify cracks in aircraft structures. These X-ray emissions can directly affect a UV sensor if a UV vacuum tube (basically a Geiger counter) is utilized as the sensing element, which is the common case. IR sensors and electronics can also be affected by X-rays. A recent test at Edwards AFB indicated that a UV/IR detector can be affect by, and alarm to, 160 KeV X-rays that originate at over 200 feet distance from the detector. Also, detectors may be influenced by the EMI emitted from an X-ray machine's power supply.

Figure 5. MHu 83B-E Bomb Lift Truck (note hot exhaust manifold that is exposed during operations)

Figure 6. A-M32A-95 Turbine Compressor (note large exhaust area flame/back-fire events occur)

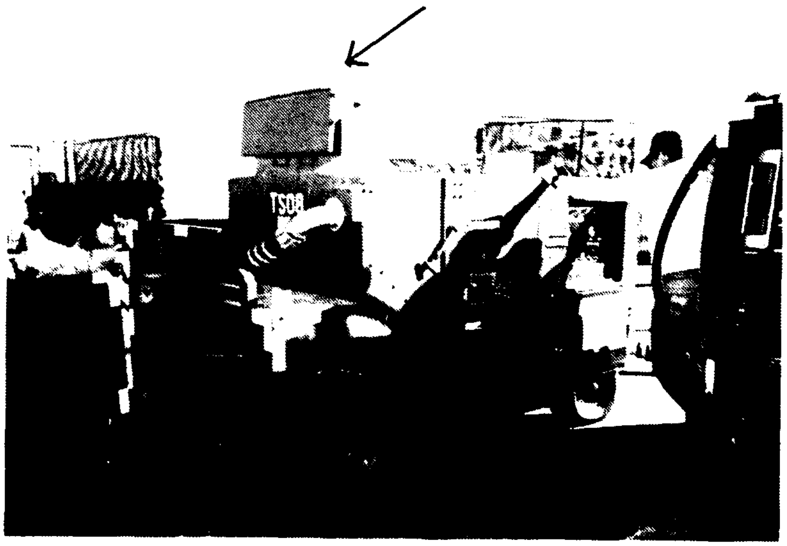

Figure 7. NF2 Light-All Cart with 400W Hg Vapor Lamps

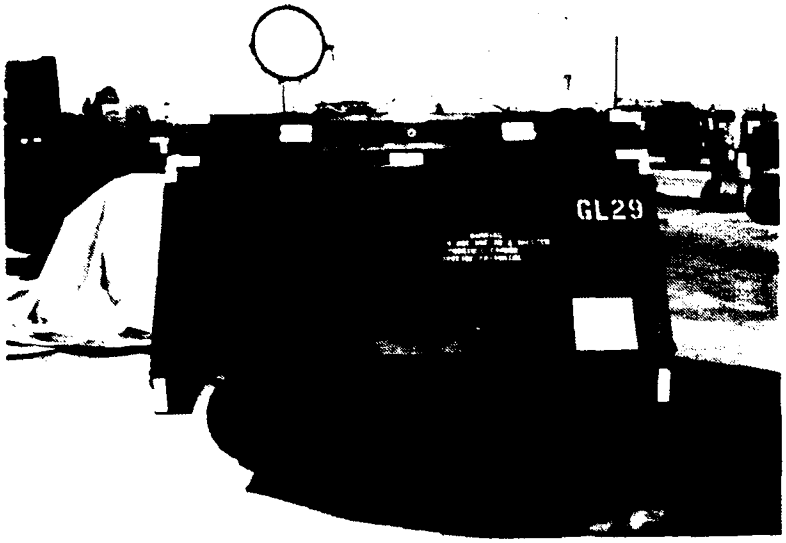

Figure 8. TF-1 Light-All Cart (uses 1000W Metallic Vapor Lamps)

Figure 9. MA1A Gas Turbine Compressor

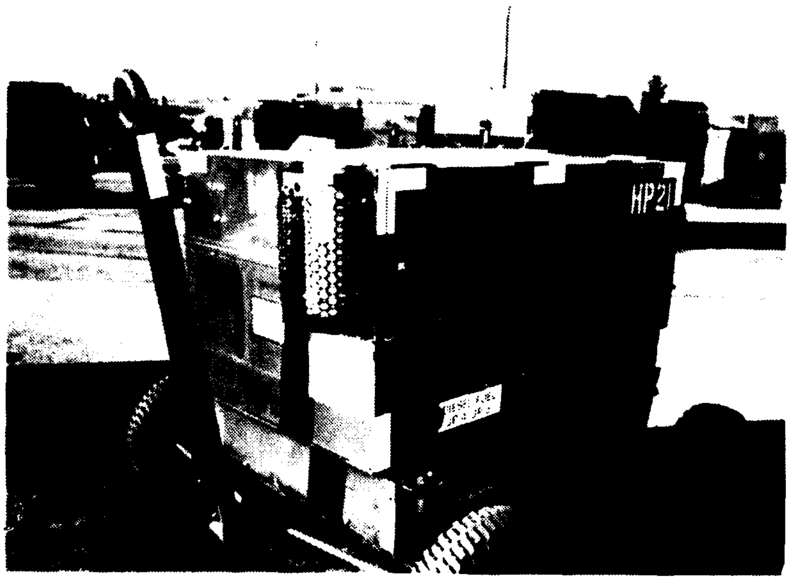

Figure 10. Air Compressor that uses JP-4

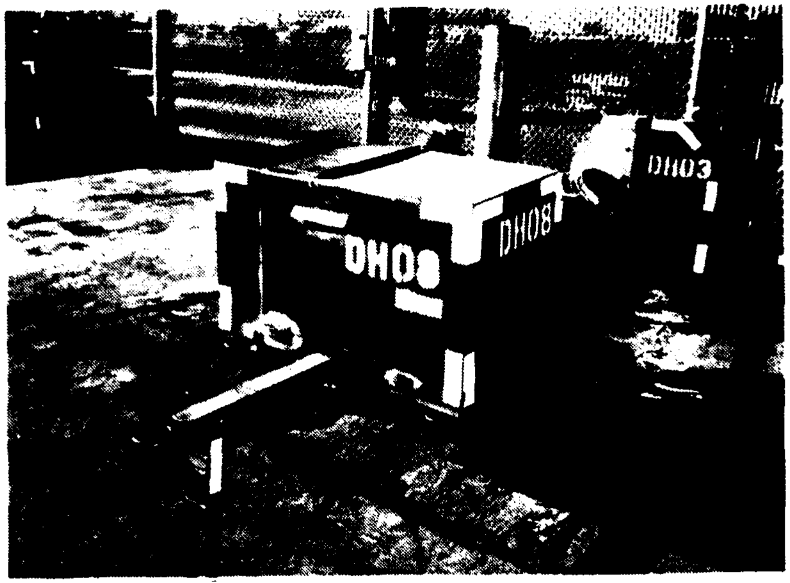

Figure 11. A-M-32-86 Generator

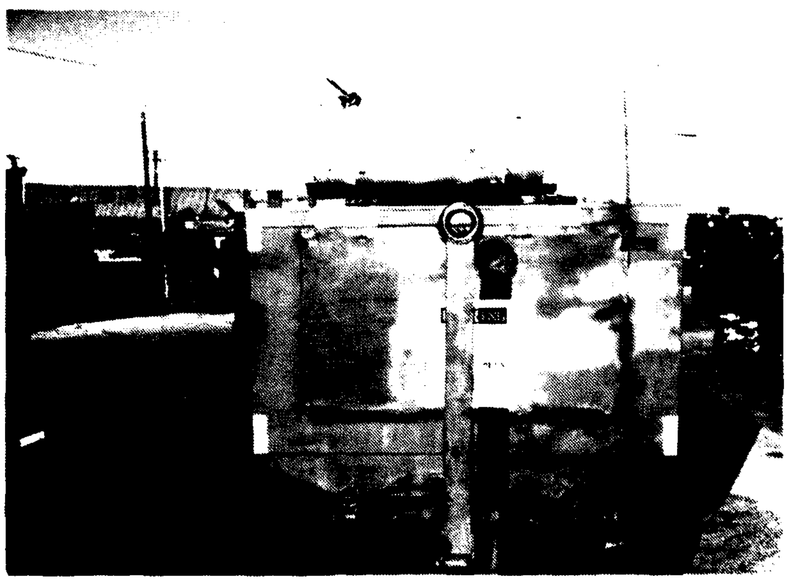

Figure 12. MJ2A Hydraulic Test Stand

Figure 13. MC2A Air Compressor

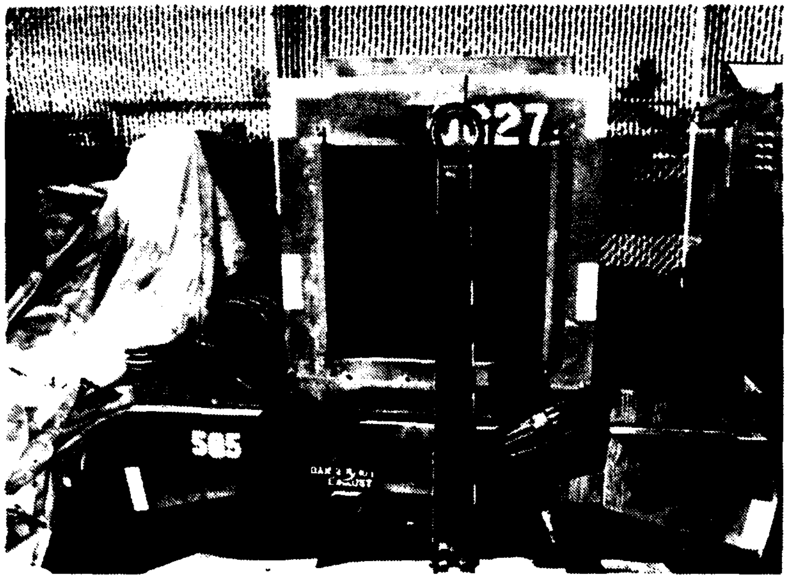

Figure 14. A-M32A-86 Generator

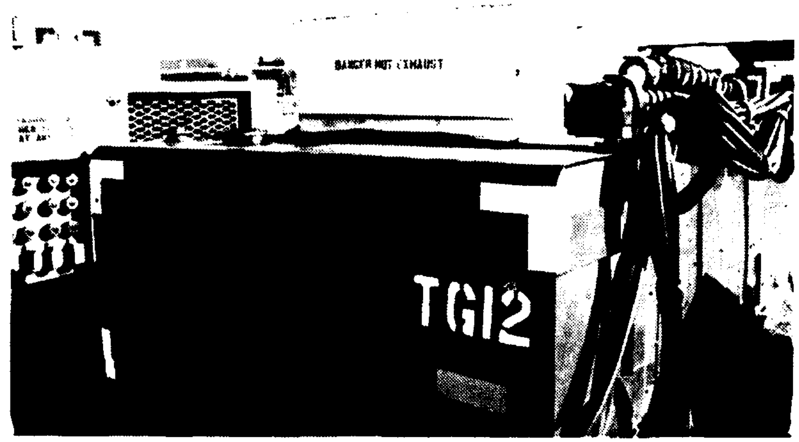

Figure 15. A-M32A-60 Power Cart

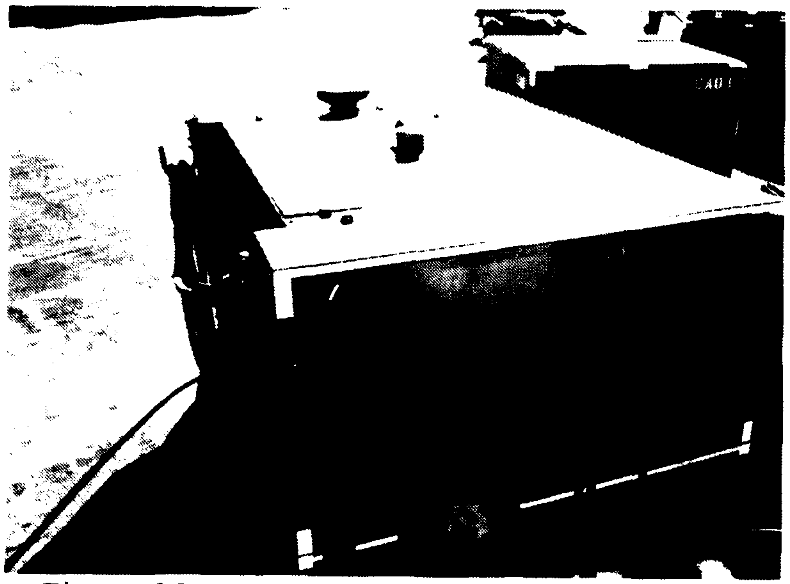

Figure 16. TTu-228B-E Hydraulic Test Stand

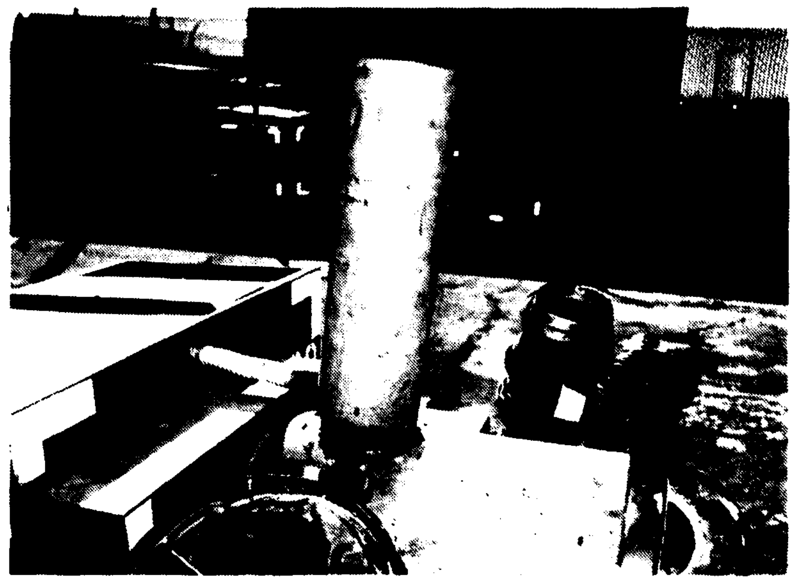

Figure 17. H-1 Heater Exhaust

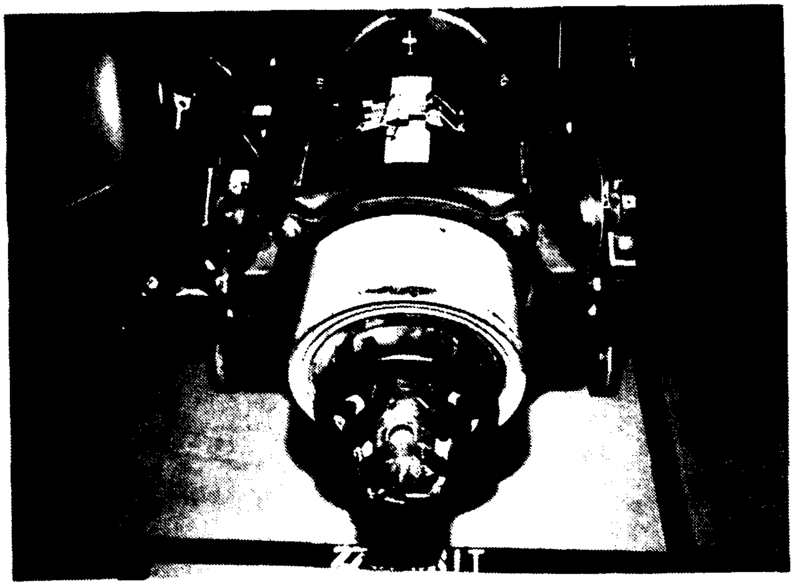

Figure 18a. Sperry 200 KeV X-Ray Unit

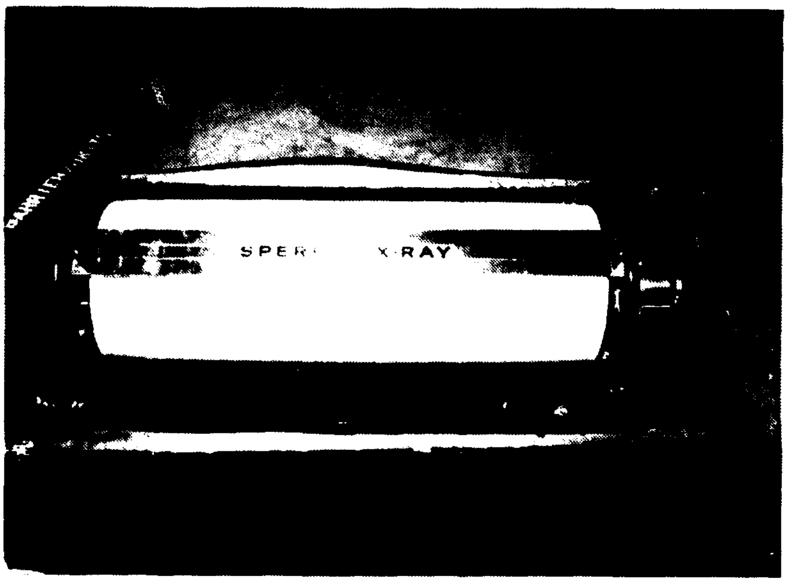

Figure 18b. Sperry 300 KeV X-Ray Unit

It is important to identify all possible sources of radiation(s) that can be detected by an optical fire detector, and to specify their emission characteristics to such a degree that specifications can be written for false alarm immunity qualification tests that can be easily conducted by the manufacturer or a certified testing laboratory.

From October, 1986, through September, 1988, 22 false alarm/false dump events were reported by AF bases to the Navy Safety Center (these data are only available through appropriate government channels). About half of the events were caused by mechanical and environmental problems and the other half due to lightning, light sources, welding and engine exhaust emissions.

In addition to these 22 reported false alarm/false dump events other events have occurred in AF hangars during the past 1-2 years. Examples of these "other" events were obtained during conversations with AF personnel and fire detector suppliers who were knowledgeable of the events. One or more events occurred at Beale AFB, Lajes AFB, Wright Patterson AFB, Luke AFB, Hickham AFB, Andrews AFB, Tinker AFB, Kadena AFB, Edwards AFB, Osan AFB, Masawa AFB, and Air National Guard hangars at St. Louis, New York, Syracuse and Pittsburgh. Some bases experienced many false alarm events and disconnected all detectors.

The following causes of the above events were identified by AF and industry personnel: (1) hot engine exhaust during aircraft start-up, thus setting off overhead thermal gradient, rate-of-rise detectors; (2) faulty electronic components in controller causing cross zoning of detector outputs; (3) X-rays 160 KeV X-ray NDI device; (4) flames and IR emission from overhead heaters at start-up; (5) arcing of transformer on power pole at 100 yards distance from hangar; (6) sodium vapor lamps without proper quartz lens covers, thus allowing UV emission; (7) UV emissions of sodium vapor lamp starter; (8) concurrent welding and heat treating of aircraft structure; (9) water leakage into controller and detectors; (10) photo flood lights without glass shatter shields that were used in making training films; (11) dirty lenses on detectors (poor maintenance) thus causing fault alarm to go off in fire station, resulting in fire department scrambles; (12) Rf transmissions of 5-Watt hand-held Walkie Talkies; (13) lightning; (14) flame/exhaust from M-60 and other JP4/Diesel AGE equipments; (15) welding in the distance and hot manifold of front loader close to detector; and (16) mechanical failure of components in controller due to induced vibrations from aircraft engines.

The false alarm/dump events associated with overhead thermal gradient detectors were due to hot aircraft and AGE exhausts. According to a Fire Department staff member at a California AFB, at least 10 such events occurred consecutively, resulting in the loss of 1500 gallons of AFFF. About 20 other events followed due to the same cause but suppressant dumps were curtailed through manual intervention. The fire protection system was deactivated awaiting detector replacements and/or redesign.

The above events may not have resulted in great financial loss, but they did curtail the utilization and readiness of mission-essential aircraft.

A summary of false alarm and false dump events at Air Force bases was requested during the Phase I study. These reports were not available in time to be considered in the Phase I study. They will be available however, for use in a Phase II effort.

In this Phase I study possible false alarm sources have been divided into two categories: (1) discrete sources, and (2) complex sources. The former category consists of those items that are readily available and can be mounted in fixtures in a test facility and exposed to a detector without any obstruction of field-of-view. Various types of lights fall into this category.

Complex sources are those that cannot be easily mounted in a laboratory test fixture and which may be spurious emitting sources as opposed to continuous emitting sources such as lights. Examples include arc welders, acetylene torches, matches, kerosene heaters with fans, EM emissions from jammers and communications and backfire/wet-start events from AGE and aircraft engines.

1. Discrete Sources Of Radiations That May Affect Optical Fire Detectors

The following discrete sources were identified during AF base visits/inspections and from reviews of past work on this subject (References 3 and 6). These are potential false alarm sources that warrant further investigation of spectral emissions and effects on optical detectors. The list is not all-inclusive and would possibly be expanded at the beginning of a Phase II effort.

TABLE 1. DISCRETE FALSE ALARM SOURCES

1.	500 - 1500 W Quartz Halogen	12.	Ambulance Strobes
2.	400 - 1000 W Mercury Vapor	13.	Vehicle Spotlights
3.	1000 W Multivapor	14.	Movie Lamps
4.	Fluorescent	15.	600 W Quartz
5.	Electronic Flash-Graflite	16.	Xenon Lamps
6.	Flashlights	17.	High Pressure Sodium Lamps
7.	Vehicle IR Lights	18.	Aircraft Landing Lights
8.	Vehicle Headlamps	19.	Aircraft Tail Lights
9.	Incandescent 100 W Rough Service	20.	Aircraft IFR Light
10.	Red Dome Lights	21.	Aircraft Strobe Lights
11.	Ambulance/Police Car Light Bars	22.	Aircraft Wing Tip Lights

Some sources are included because their thermal emissions may be sufficient to affect a detector, especially if they are located near the detector. Others are associated with equipment such as the Light-All Cart that can have as many as six 1000-Watt Mercury Vapor or Multivapor Lamps, thus producing heat, and possibly UV if a lens is broken, cracked or missing.

2. Complex Sources Of Radiations That May Affect Optical Fire Detectors

The following potential complex false alarm sources were identified during AF base visits/inspections and from reviews of previous false alarm emission tests (References 3 and 6). Some of the listed complex source "backfire/wet-start events" are actual fires that only differ from major fire threat events in their size and duration. They can, however, evolve into major fires, especially from JFS- and AGE-related events. The following table of complex sources may be expanded at the beginning of a Phase II effort.

TABLE 2. COMPLEX SOURCES OF FALSE ALARMS

1. Lit Cigarette and Cigar
2. Wood and Paper Matches
3. Lighter
4. Electric Arc 1.2 cm gap, 4000 V
5. Acetylene Welder, 00 Tip, 16 x 150 mm Flame
6. Arc Welder, 4 mm Rod, 300 Amp
7. Rifle Flash, Consecutive, M-16/50 Cal
8. Dash 60 AC Power Cart Backfire Event in Manifold; Also, Hot Manifold
9. Jet Fuel Starter Fire Events (See Following Subsection)
10. X-Ray Diagnostic NDI, 160-300 KeV
11. EM Emissions From Radar, Jammers, Communications, Hand-Held Radios, etc.
12. IR Emissions From Aircraft Jammers, LANTIRN, ALQ-184, etc.
13. Sunlight (Direct and Reflected)
14. Aircraft Engine Wet-Start or Backfire in Exhaust
15. Aircraft Engines Starts; Power Levels 20-80 percent
16. Afterburner Flame From F-4/F-15/F-16/F-111 in distance and in facility.
17. Radiant Kerosene Heater 70,000 BTU with Fan
18. Manifold/Exhaust IR & UV Emissions From Front End Loader, Air-Conditioning Cart, Steam Cleaner Cart, M-60 AC Power Cart, Heater Cart, Generator Carts, Pneumatic Carts, Blower Carts,
19. Reflections From Bright Colored Objects

Some of the above listed complex sources would be difficult to locate and simulate in the Phase II laboratory for false alarm immunity tests. Testing for immunity against X-ray machines should be performed in an appropriate NDI facility. If specified by the Air Force, the electromagnetic immunity requirements would be imposed on the detector supplier through Mil-Std-461 and -462. Detectors that satisfy these military standards would be immune to possible alarms/false dumps due to extraneous electromagnetic interference as has been previously identified from such items as hand-held radios and X-ray NDI units. There is also some suspicion that aircraft radar and communications jammers may affect optical fire detectors that are not EMI protected.

In conducting the actual measurements of detector response to the above sources, distances from detector to source(s) should be specified as well as the time of exposure(s), degree of chopping if any, transient on and off situations, and number of repeatable tests. Combinations of various sources would also be specified. Ability of a fire detector to identify a threshold fire while in the presence of the above potential false alarm sources is also an important performance requirement.

a. Complex Sources Associated With Aircraft Ground Support Equipments (AGE)

As stated above in Section III-B, approximately 20 fire events associated with AGE items were reported over the past 10 years that resulted in equipment damage and at least Class C financial loss. During the course of the Phase I effort, discussions were held with maintenance support personnel at the AF bases stated in previous sections. It was also concluded from these discussions that backfire or hot-start fire events are not rare, especially from equipments that utilize gasoline, diesel and JP-4 fuels.

The AGE backfire events usually begin with an explosive phase that emanates from the exhaust manifold. A plume of flame of a few square feet lasts a few seconds to minutes depending upon the quantity of unspent fuel or other combustible products that are present.

Most fire detectors are designed to see 16-100 ft^2 fires at distances as great as 150 feet in about 5 seconds. Therefore, a small fire of only 1-4 ft^2 at a distance of less than 25 feet will be detected within a few seconds, depending upon whether the detection logic uses time gating. It is apparent that these backfire, hot-start engine events on AGE items may be seen by a UV, IR and/or UV/IR detector, thus resulting in the activation of alarms and release of the fire extinguishing agent.

Such fire events are usually not difficult to extinguish with hand-held extinguishers, although there have been some reported events where the resulting fire completely engulfed the AGE item and ignited other flammable materials in the hangar (from data provided by the Navy Safety Center: available through appropriate government channels and not available to be included herein).

These events are actual fires, yet, in some cases may be too small to warrant a major suppressant dump. When these type of events occur, the detection subsystem should rapidly identify the fire, initiate appropriate alarms in the hangar and fire station, and "monitor" the size of the fire until it reaches the specified minimum fire threat size, at which point the fire suppressant would be released. The fire detection subsystem should therefore be able to discriminate the type of fire event, as well as its location and size/growth.

Figures 9-17 show several AGE items that are associated with such events as described above. These AGE items were reviewed at all the AF bases visited during the Phase I study.

Figures 6 and 9-17 show those AGE items that have hot exhaust manifolds that radiate in the IR region. Each of these radiative hot surfaces should be measured for temperature and broad-band wavelength emissions. Since the emission spectra should be very similar, the objective would be to determine the most intense and largest radiative surface from these hot sources so that a "worst-case" model of such infrared emitters can be designed and simulated. Other IR emitters such as aircraft engines, jammers, heaters and light sources would also be included in "worst-case" scenarios.

b. Complex Sources Associated With Aircraft

The aircraft-associated complex sources and events include possible activation of the afterburners, hot exhaust nozzles, JFS fires, nacelle fires, engine backfires/wet-starts, emissions from jammers and communications, emissions from pods such as LANTIRN, radar emissions, hot brakes, and many other aircraft unique items.

As indicated in the above list of complex sources, there are a number of aircraft-associated events that result in real fires and/or in explosive events that resemble a "belch" of flame and smoke and last for seconds to minutes. The sustained events that are relatively large in areal extent and prevail for many seconds in duration would be seen by almost any detector and need to be extinguished rapidly. Smaller events may not require a major dump of suppressant because hand-held extinguishers may suffice or the fire may self-extinguish in a short time. This is a prime example of the need to qualify both the detector and the complete fire detection system, including detector configuration and detector voting and other electronic "decision-tree" logic in the controller. A single detector may "see" the event and dump when the situation does not warrant such action. A detection system however, may be designed to be "smart" and only alarm to such events instead of activating a full dump.

D. LOCATION AND AVAILABILITY OF AIRCRAFT, FACILITIES, AGE AND FALSE ALARM SOURCES - TECHNICAL REQUIREMENTS 2 AND 3

Most Air Force bases have a variety of AGE items and different types of hangars and support facilities. However, few bases also have a large complement of different types of aircraft. Cost was the major factor in determining feasibility of the Phase II effort, and included considerations of possible Air Force base location(s) that could be used for the field measurements.

CONUS, PACAF, and USAFE bases were reviewed as possible locations for the field false alarm measurements. Bases such as Hickam, Norton, McClellan, Beale, Edwards, and Tyndall were visited during the course of this study. PACAF Headquarters was also visited, as well as a Canadian NATO base at Lahrs, West Germany.

Edwards Air Force Base near Lancaster, California, offers a large variety of aircraft, facilities, and false alarm sources. The aircraft located at this base includes the following, along with their unique, if appropriate, support facilities and equipments: F-15, F-16, F-4, B-52, KC-135, F-111, T-38, Y-A7, A-37, B-1B, B-2 and a variety of helicopters. Two "hush houses" (engine test facility) and a number of outside engine test stands are also available for engine emission measurements, including afterburner. A Non Destructive Inspection (NDI) X-ray facility is available to test X-ray effects on detectors and electronics.

No commitment, however, was made (or could be made) during the Phase I effort by Edwards AFB or any other base to make aircraft and facilities available for a Phase II effort. A test requirements plan should be developed at the beginning of Phase II that specifies each and every task that would be performed and what facilities, aircraft and equipment would be required. The AF would then make the decision on where the field program would take place. and make the necessary arrangements.

This Phase I report could serve as an introduction to the field measurements requirements. As discussed in more detail below, the field program should include emission measurements from at least one representative fighter aircraft, although it would be desirable to include a variety of aircraft. The F-15, F-16 or F-111 would be the best options because they have long, intense afterburner flames. Should there be major differences in the other discrete and complex false alarm sources carried by each aircraft, it may be necessary to utilize more than one fighter aircraft for these measurements. Also, at least one large body aircraft should be subjected to engine and other subsystem emissions measurements. The availability of both types of aircraft for spectral emission measurements may be difficult to schedule, but past field testing during the Hardened Aircraft Shelter Program was accomplished at USAFE and RAF locations with relatively short notices of request.

If Edwards AFB is selected by the Air Force as the location for field test measurements during the Phase II effort, it would be highly desirable (cost-effective) to also conduct emission measurements on the B-2 and its support hangar/equipments during the same time period when other aircraft and false alarm measurements are being made.

Although it may be more efficient and cost-effective to conduct all the necessary field measurements at one location over the shortest period of time possible, the various parts of the field measurements program could be separated in both content and time. The aircraft emissions measurements part of the effort could be conducted independently of the non aircraft discrete and complex false alarm source and AGE item measurements. The aircraft engine emission tests would be conducted in a hush house for fighter aircraft, and in their respective hangars/docks/ramps for large body and/or B-2 aircraft. Other aircraft-associated emissions could be made in other facilities or perhaps outside. Should the necessary fighter aircraft not be available, at least the UV and IR engine emission measurements could be made during routine engine test stand runs. The duration of measurements on each aircraft, including engine and all other aircraft discrete/complex sources, would be approximately 4-5 hours maximum (based upon similar aircraft measurements made during the HAS FPS development effort).

A preliminary concept of the field testing procedures on all potential false alarm sources, including aircraft, is discussed later in this Section.

E. DETERMINATION OF WHAT OPTICAL MEASUREMENT EQUIPMENTS ARE NECESSARY TO CONDUCT THE PHASE II EFFORT - TECHNICAL REQUIREMENT 4

The general approach taken in this analysis was to evaluate equipment requirements based upon the following considerations: (1) ruggedness of the field instrumentation; (2) selection of equipments that were very specific to the required measurements--no greater capabilities than were needed for the project; (3) utilization of field equipment in the qualification testing laboratory in order to reduce unnecessary duplication; and (4) cost. The following were the results of these tradeoff analyses.

The recommended instrumentation for the false alarm field measurements and the qualification test procedures development parts of the program are discussed below. The recommended IR instruments would provide sufficient broad-band spectral radiance information to conduct the proposed program and to establish qualification test procedures for detector immunity. The recommended UV instruments would provide sufficient high-resolution spectral data.

1. Pyrometers

The recommended complement of sensors for measuring the temperatures of radiative surfaces and effluents either by contact, or remotely with an optical pyrometer, are as follows:

a. By Contact: Digital thermometer, capable of temperature measurements up to 2500°F, with the following set of probes for various possible modes of contact.

1. Probe 1 (100°F to 500°F)
2. Probe 2 Immersion Probe (100°F to 1700°F)
3. Probe 3 Surface Probe (100°F to 500°F)
4. Probe 4 Air Probe (100°F to 1500°F)
5. Probe 5 Piercing Probe (100°F to 1500°F)
6. Probe 6 Exposed Probe (100°F to 1700°F)

b. Optically: Optical pyrometer, which can measure temperature remotely from 100°F to 1600°F, can be coupled into a computer, and has multi-function display, reflected temperature compensation, 8- to 14-micrometers spectral response, 1-inch spot diameter at 3 feet, and analog and digital outputs. The following support items should also be provided:

1. 110 V AC adapter
2. 120-inch computer cable and adapters
3. 5 1/4-inch software disc for data transfer to Lotus
4. Blackbody, 6-inch square, 150° to 700°F, 110V.

The above set of instruments, all of which are hand-held, enables determination of location, hot-gas effluents, or anything suspected of having a source of IR radiation at 4.3 micrometers. Having measured the temperature, by application of the measurement to determine the black or gray body radiance from a body at that temperature, it can be determined whether that body could be the source of a false signal at 4.3 micrometers. Even though the optical pyrometer measures the radiance in the 8- to 12-micrometer IR band, from this the radiance at 4.3 micrometers can be calculated. It may be desirable to also use an IR spectrometer for certain field and lab measurements, especially for measurements in the 2- to 5-micrometer range.

2. Instruments For UV Measurements

There are two types of UV instruments recommended the field measurements: (1) high-resolution UV multispec spectrograph, and (2) hand-held UV radiometers. They provide reliable radiance measurements, can be calibrated in the field, and can be coupled to a computer.

The high-resolution spectrograph, covering 180- to 400-nanometer range through the near IR, is recommended for this program. The "multi-spec spectrograph" should also include accessories that include detector arrays, filters, gratings, slits, fiber optics cables and lenses.

The hand-held UV equipments recommended for far UV measurements cover the spectral bands of interest as follows: (1) peak wavelength 254 nanometers; (2) peak wavelength 300 nanometers; (3) peak wavelength 365 nanometers.

Two different radiometers and two separate sets of interchangeable sensors are required to cover the full band of measurements summarized above.

A field calibration system is required to provide calibration for the long-, medium- and short-wave bands. A separate source should be used for each of the three UV bands. The calibrations should be referencible to NBS standards. In this way, absolute levels of radiances under investigation can be obtained for the bands measured. The following equipment is recommended:

1. High-Intensity UV Radiometer: High-Intensity (0-200 milliwatts/cm^2) with interchangeable sensors at 254-, 300-, 365-, 405- and 450-nanometers.

2. Low-Intensity UV Radiometer: 0-20,000 microwatts/cm^2: with interchangeable sensors at 254-, 300-, 365-, 405- and 450-nanometers.

3. Field Calibration System: Long-, Medium- and Short-Wave.

The equipment listed above would serve in both field and laboratory applications. In addition, standard electronics, power, mechanical and automated computer data collection equipments are required to support the laboratory test procedures development effort.

F. LABORATORY SUPPORT ITEMS - TECHNICAL REQUIREMENT 4 (CONTINUED)

The recommended facility for the development of qualification test procedures would consist of basic laboratory tools and supporting items, similar to those found in any aerospace quality assurance and test facility. The equipments recommended below are those "types" of support items that would be needed to develop simulation devices, laboratory test fixtures and data recording systems.

Work Benches: Antistatic mats; drawers; isolation transformers; Lights; magnifier lights; power strips; power supplies; chairs.

Hand Tools:	Allen wrenches; calculators; desoldering tool; flashlight/pen lights; inspection mirror; orange sticks; pliers/long nose/std; screwdrivers; shrink tubing; socket sets; soldering irons; tool boxes; wire wrap tools; wire racks; electronic circuit tools; standard tool sets.
Facilities;	Battery back-up system; 10 KW generator (necessary to operate multiple 1-1.5 KW light sources and IR heat sources simultaneously); air conditioning; heating system; line transformers; overhead lighting.
Power Tools:	Air compressors; drill press/bits; metal bender; metal saw; jig saw; power screwdrivers; radial power saw; skil saw.
Lab Test Area:	Antistatic mats; separator walls; tape recorder; cameras and film; breadboarding items; clamps; clock; elapsed time meters; event recorders; extension ladder; extension cords/boxes; fire extinguishers; eye protectors; fire blankets; fire bench; fire pans; burn unit facility; fire proof cabinet; first aid; intercom headsets; lab clothes; oscilloscopes; overhead lighting; PA system; power supplies; power strips; stop watches; telephones; television monitor; VCR; temperature chamber; optical bench and support items; video taping system with audio; work tables; automated data acquisition and recording; electronic meters and measuring devices.
Photography:	35 mm camera; macro lens; wide angle lens; drapes; lighting/reflectors; film; tripods.
Welding:	Cart; cabinet with supplies; gloves; helmets; rods; tanks.
Computer:	386 with 80 Megabytes hard disc, 25 MHz speed, 4 Megabytes RAM; Modem; VGA monitor; Word Perfect; Lotus 123; Timeline; printer (24 pen); optical scanner to digitize recorded/plotted data for computer storage and processing.
Simulation Devices and Fixtures:	Calrod hot plates with variable power supplies; array of various light sources; heaters; fans; reflectors; choppers; motors for fixture rotation; mechanical fixtures; UV sources; IR sources; optical filters; optical measurement equipments as discussed earlier; list of simple false alarm sources stated herein; remote controlled fixture mountings on tracks to move various sources into detector field-of-view and to change distances and angles of emitters.

Components: Assortment of standard electronic and mechanical parts.

The above tools and facility items are standard electrical/mechanical laboratory items. Most are available at low cost through manufacturers or through used equipment outlets (or through GFE). The track-mounted fixture arrangement (similar to a high-quality train set) would be custom designed, but the parts and controls are readily available. This type of mobile track is commonly used in industry for production and testing puposes.

It may not be necessary to include any burn-test capabilities in the test facility, as such measurements may best be performed during the field measurements program at selected Air Force base(s). This is especially true of the "explosive" event simulations that should be conducted under Fire Department safety constraints in a safe area.

G. DEVELOPMENT OF FIELD TESTING PROGRAM - TECHNICAL REQUIREMENT 5

The optical equipment and data recording and processing system described above were selected for dual application: (1) field testing, and (2) laboratory test procedure development. One approach that appears to be both cost-effective and efficient in fielding the measurement equipment is to use mobile platforms (carts) and a medium size van. In this approach the measurement equipment would first be delivered to the qualification test laboratory location where they would be integrated into a portable field configuration, mounted on appropriate mobile, vibration resistant benches or tables, calibrated against IR and UV sources, and performance tested. After this initial check-out is completed, the equipment would be transported via van to the Air Force base where the field measurements would be conducted. The use of hand-held measurement devices and a mobile field instrument approach provides flexibility in moving from one area on a base to another where different equipment, aircraft, AGE and other false alarm sources may be located.

The field tests can be separated into major segments depending upon the availability of aircraft, facilities, AGE and support personnel. The major segments of the field testing can be divided as follows:

1. Fighter Aircraft (one or more) Discrete and Complex Sources

   A. Engine measurements in a hush house
   B. Measurements of lights, communications, navigations, jammers and other aircraft subsystems in either the hush house, in a separate facility or on the ramp.

2. Large Body Aircraft (one or more) Discrete and Complex Sources

   A. Engine measurements in hangar or outside on ramp.
   B. Measurements of lights, communications, navigations, jammers and other aircraft subsystems in either a hangar or outside.

3. AGE Discrete and Complex Emission Sources

   A. AGE items such as those listed in Figures 5-17 would be measured for their respective UV and IR emissions in an outside AGE yard facility.

4. Hangar, Facility Utilities, Tools, and Support Equipment Discrete and Complex False Alarm Source Measurements

   A. These measurements would cover all the lights listed in the discrete source table in Section III-C-1. The measurements would be in-situ, if possible. However, many of the items would be mounted in the qualification test laboratory where they would be measured and used in detector testing.

5. Complex Sources Associated with Explosive Events Such as Those from Aircraft JFS fires, Engine Wet-Starts, and AGE Engine Wet-Starts/ Backfires

   A. These measurements would be made under supervision of Fire Department personnel at either an Air Force base or in a controlled and local Fire Department approved area and with approvals for the test procedures. Simulations of the aircraft and AGE events would be developed and tested. Optical measurements would be made of the events.

Any one of the above five categories of field measurements could be conducted independently of the others at different locations and at different times. However, it would be most cost-effective to conduct as many of the measurements as possible at one location in a consecutive or concurrent mode.

1. Fighter And Large Body Aircraft Measurements

These measurements include both fighter and large body aircraft as indicated above (Segments 1 and 2 of field testing). The fighter aircraft of most interest includes F-4, F-15, F-16 and F-111. UV and IR emissions from these aircraft are probably equal to or greater than those from other Air Force aircraft. These aircraft were also selected for possible field tests because they are the predominant aircraft that occupy Hardened Aircraft Shelters and Flow-Through-Alert Hangars that require fire protection systems.

A hush house and/or open air engine test cell (see Figures 19-24) could be utilized at several AF bases for fighter aircraft emission measurements. In a hush house, the optical measurement equipments would be located away from engine vibration and blast, possibly in the corner at a 45-degree angle to the engine nozzle. The data recording equipment would be located in the control room. Fiber optic cable could be used if additional protection of the optics instrumentation is required.

Fighter aircraft would be brought into the hush house tail first and located that the exhausts point towards the exhaust vent, and tied down. A 45- to 90-degree field-of-view would be required for exhaust emission tests.

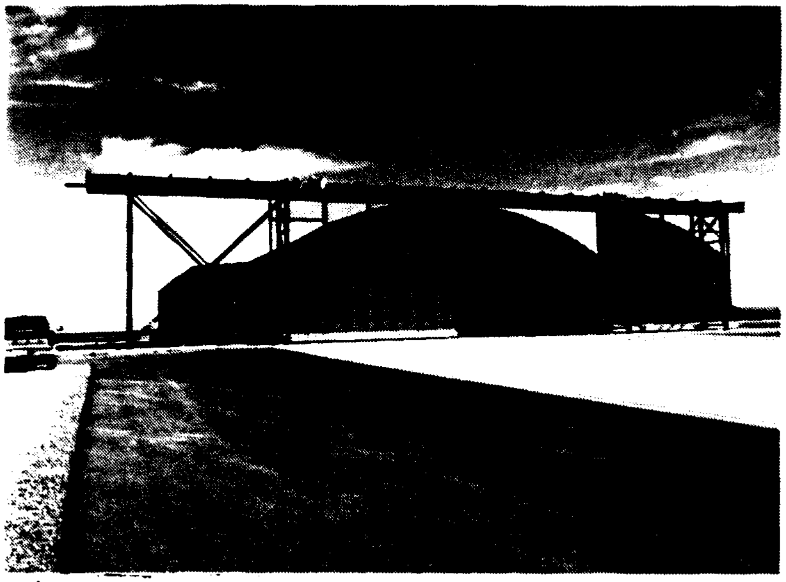

Figure 19. Front of Hush House at Edwards AFB

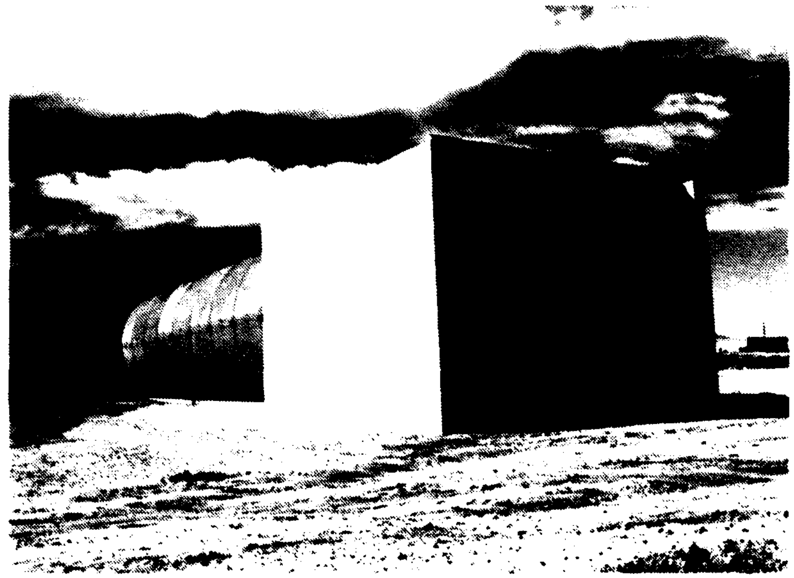

Figure 20. Exhaust Vent at Rear of Hush House

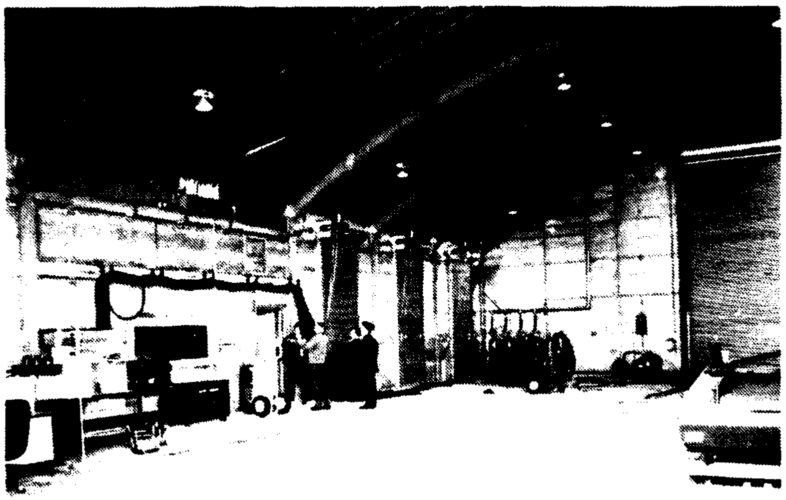

Figure 21. Inside Hush House; View of Control Room

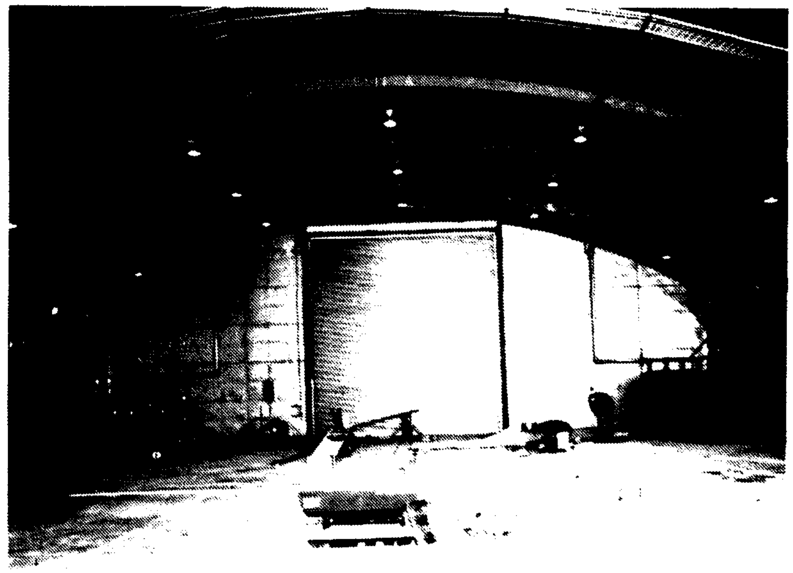

Figure 22. Inside Hush House; Aircraft Tie-Down Area

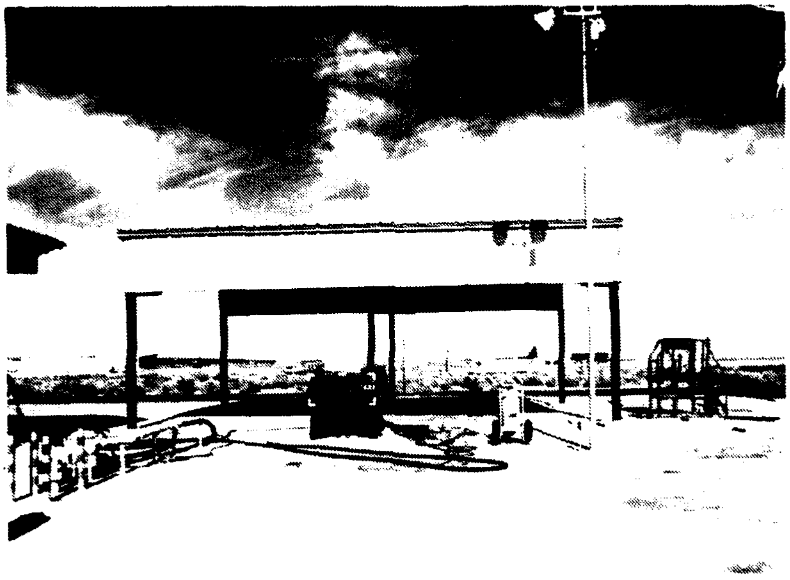

Figure 23. Engine Test Stand Area

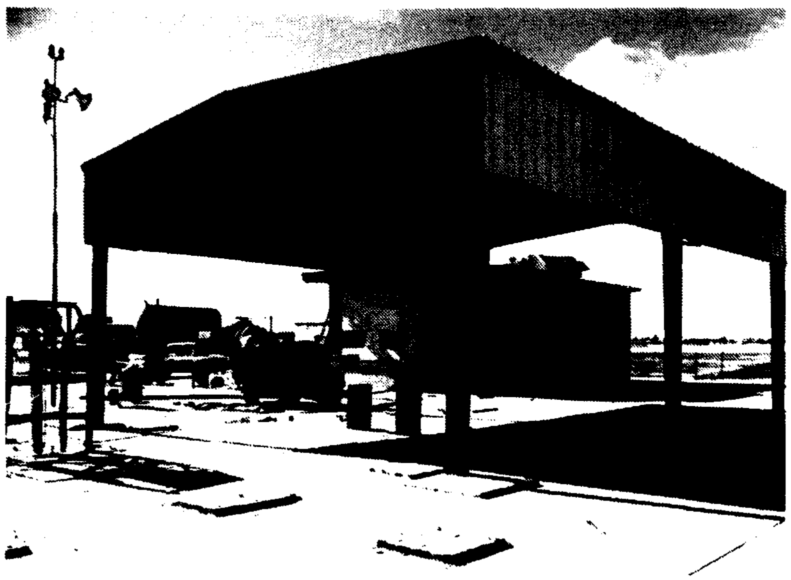

Figure 24. Engine Test Stand
(engine would be mounted
on the two piers)

Measurements would be made in the UV and IR of the tail exhaust nozzle and engine effluent. After start, the engines would be placed into idle at about 20-25 percent power level and held in this condition for 5 minutes. The engine(s) would then be increased to 40 percent, 60 percent and 80 percent power levels and held in these levels for 3 minutes each. After the 80 percent step is completed, the pilot would place the engine(s) into the AB mode, hold this condition for 2 minutes, and then throttle down again to idle and then to off. These procedures are similar to those used in tests conducted at Bitburg Air Base on the acoustic emissions of an F-15 engine and at UK RAF bases on the Tornado engine UV/IR emissions during the development of the HAS Fire Protection System requirements.

After the engine UV and IR emission tests are completed, the engines would be shut down and the optical measurement equipments moved to various locations around the aircraft where maximum field-of-view can be obtained of various light and jammer sources on the aircraft. Landing lights, wing lights, tail lights, strobe lights and other possible sources of IR and UV would be activated and measurements taken. The IFR light may not be easily seen by the test equipment and may have to be independently tested later in the test procedures laboratory. Other lights associated with the facility itself would also be measured for their IR and UV emissions. Any IR emitting-jammers and other type of pods such as LANTIRN and ALQ-18 would also be tested for their emissions, but these measurements could be made in other facilities with different aircraft at different times.

Measurements of the engine and complex and discrete source emissions from large body aircraft, other than the B-2, would be made in either their respective hangars or on an outside ramp. At least two aircraft, in addition to the B-2, would be selected by the Air Force. The engine measurements could be made on an engine test stand during scheduled test runs.

B-2 measurements would be made in the aircraft's respective hangar. In this case, all the associated AGE items, tools, equipment, facilities, utilities and subsystems that are unique to the aircraft would be measured in a stand-alone measurement task. This task would be scheduled separately by the AF. Either Edwards AFB or Whiteman AFB would be used for this task.

If an open air engine test cell is used for any of the engine emission measurements discussed above, there is adequate safe space for the equipment to be located away from the engine exhaust to protect the optics and electronics. The hand-held measurement equipments discussed in the previous Section would be beneficial for such measurements. This option can be implemented at several AF bases for both fighter and large body aircraft engines.

2. AGE Measurements

The optical measurements equipment would be moved to the AGE storage/ maintenance yard where an open, roof-covered dock area is usually located (Figure 25). This area would be "curtained-off" around the measurement equipment. Each AGE item (Figures 11-22) would be brought into the curtained area, powered-up, and operated for about 10-15 minutes each. Of particular

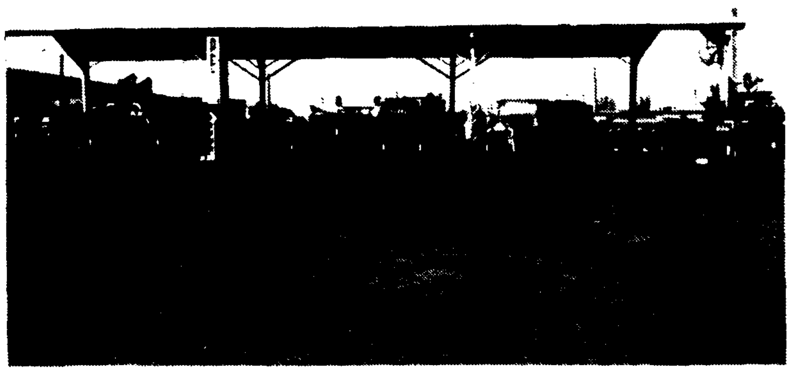

Figure 25. AGE Storage Yard (where emission measurements will be made)

importance is the thermal (IR) emissions of exhausts and manifolds and possible flame (UV and IR) emissions. Some AGE carts, such as the "Dash 60," would be started a number of times to observe possible backfires.

The intent of the latter measurements is to determine a "worst-case" temperature condition and the largest physical area of the radiative sources. It is also important to determine the nature and properties of actual flame/fire events that have been observed coming from various AGE items, although these are discussed as a separate test category below.

AGE items such as the Light-Alls would be tested for both IR and UV emissions from the bulbs with and without their lens coverings. Both versions of the Light-Alls would be tested because their light sources differ in wattage and metallic vapor type, yet both produce UV emission lines.

3. Hangars, Facilities, Utilities, Tools, Support Equipments, And NDI Discrete And Complex Sources

The optical measurements equipment ensemble would be moved to various hangar, facility and base locations to measure emissions. These tests would include measurements of emissions from all hangar, facility and outside runway/ramp lights, vehicle lights, support equipment emissions, AB emissions in the distance, welding sources, and other items listed in the tables in Section III-C. Special purpose items such as NDI X-ray machines would be tested in an NDI facility (Figures 26 and 27) where one or more detectors could be mounted and appropriate radiation detectors were available. Both X-ray and EMI effects would be measured, although the EMI requirements part of a detector qualification test procedure would be specifications from existing Military Standards -461 and -462.

Many of the discrete light sources would also be purchased or obtained from the AF and mounted in the qualification test laboratory. Some of these sources would include metallic vapor lamps, high pressure sodium lamps, quartz halogen lamps, movie lights, strobe lights, mercury vapor lamps, IR flashlight, police and ambulance light bars, IFR light, and many other items.

4. Explosive Fire Events Associated With Aircraft And AGE Engines

The events discussed earlier in this report that involve the aircraft engines, JFS, and certain AGE items that utilize JP-4, diesel and gasoline engines would be simulated in a fire-safe area and supervised by either AF or local Fire Department personnel. The simulation is a rather simple process that requires some brief explosive phase followed by a sustained fire lasting for a few seconds to minutes. The intent here is to develop appropriate simulation methods and at the same time determine how optical fire detectors respond to such events. These are real fire events but can be considered as either "false alarm events" (because of their relative small size and short duration, in some cases) or as fires to be extinguished via the automatic suppression system in the hangar (because of their threat). These tests would be conducted after the qualification test procedures development phase began, when a number of optical fire detectors would be available for use in the tests.

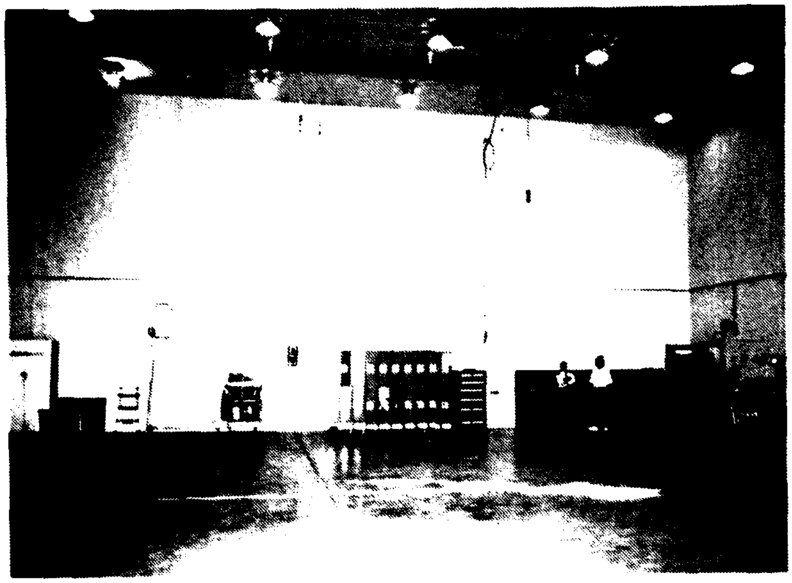

Figure 26. Inside View of NDI (X-Ray) Facility at Edwards AFB

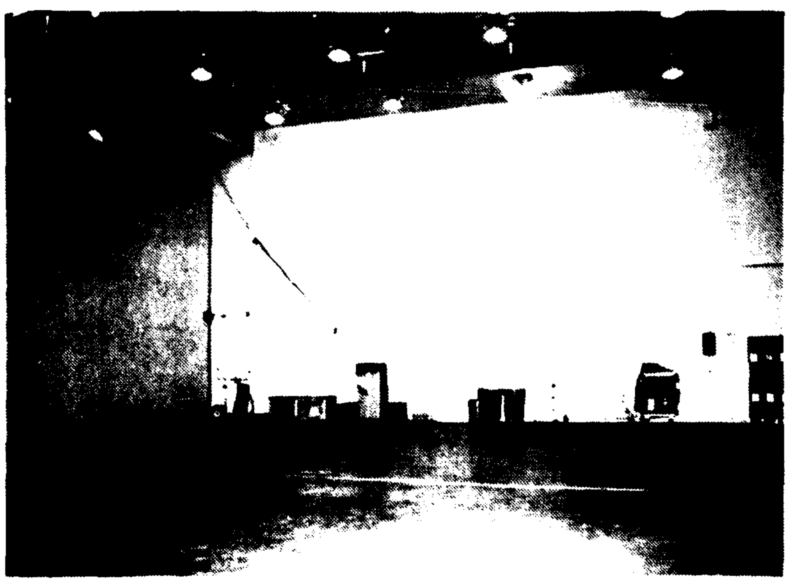

Figure 27. Another View of NDI Building

H. LABORATORY REQUIREMENTS TO DEVELOP SIMULATIONS AND QUALIFICATION TEST PROCEDURES - TECHNICAL REQUIREMENT 6.

1. Laboratory Requirements

Upon completion of the above field tests, the optical measurement equipments and data acquisition system would be returned to the laboratory and recalibrated. Data analysis would then begin on the field data.

In concert with the above data analysis, those radiation emitters that could cause a detector to false alarm would be divided into those that should be purchased and mounted in laboratory fixtures and those that must be simulated in the laboratory facility. Methods of simulation would then be developed and thoroughly tested against the field measurement data to verify similarity in physical and radiative characteristics.

Those sources that are real fire sources such as backfire events, wet-starts, and JFS fire events should be analyzed separately from other UV and IR sources because their simulation would require a special fire-safe facility or location during the development of the false alarm test procedures. This was discussed above in Section III-G-4.

It would be a goal of the Phase II effort to develop a laboratory test configuration that can be duplicated at minimum expense by detector suppliers. The facility could also be designed in such a fashion as to provide flexibility in the number, location, and time exposure of discrete and complex sources to one or more detectors.

During the Phase I study various options were analyzed regarding the location of the laboratory and what measurements had to be performed. It was concluded that the qualification test facility should be located in the geographical region where the field measurements would be made. If the AF selects Edwards AFB for the Phase II field measurements it would be cost-effective to locate the qualification test facility in the southern California area. Some supporting reasons for recommending this approach are as follows:

a. The technical staff that would conduct the field testing should also conduct the laboratory test procedures development program, as they would be most knowledgeable about the measurement equipments and measurement procedures. Minimum labor, travel and per diem costs would be realized by locating the facility in the general area where technical staff reside, and within short driving distance to the location where field measurements would be conducted. It was also assumed that follow-up field measurements would most likely be required. Therefore, cost and ability to make expeditious return visits to where field measurements are to made were prime considerations.

b. If some or all of the laboratory test procedures development work would be contracted out to the detector industry there may be an inferred conflict-of-interest.

c. The qualification test facility would be required for a period of approximately 18 months. Potential subcontractors contacted for this effort did not have available space for this length of time and would have to lease the space. Also, a review of existing equipment at potential subcontractor facilities indicated that most, if not all, needed equipment was not available and would have to be purchased.

d. Special open-air testing involving simulated fire events and pan fire calibrations could be conducted under Air Force Fire Department purview at most Air Force bases. Also, many aerospace companies in southern California have hazardous testing facilities that may be available for such tests.

e. The southern California area Air Force bases have more of a diversity of aircraft, equipment and false alarm potentials of interest to this program than any other region in the United States. The area also includes several fire protection and detection companies and a large segment of the aerospace industry. There are also major universities and support laboratories, including military certified testing laboratories for environmental, radiation and EMI testing. The existence of the B-2 at Edwards AFB also makes this geographical location desirable for a Phase II effort.

The laboratory facility would be approximately 1,500 ft^2 or less in area. Most industrial commercial complexes provide such modules that have high ceilings, large open areas, loading docks and basic power and service facilities. Such an arrangement is ideal for the needs stated herein. A laboratory layout plan should be included in any future Phase II proposal.

All the items required in the laboratory have been determined as well as the major optical measurements equipment. These are readily available and no problem exists in obtaining any equipment or support items for this program. Because the laboratory is a qualification test facility and not a research facility, the configuration and implementation are relatively easy to accomplish. It can be concluded that the laboratory facility poses no problems to the Phase II effort and its feasibility has been demonstrated.

2. False Alarm Simulations And Test Procedures Development

The end result of the work to be performed in the laboratory would be documented test procedures for each qualification test required to prove that a detector or entire detection system will not false alarm or false activate the suppressant. These test procedures should also contain stipulations as to how to simulate certain false alarm sources if they can not be easily obtained at reasonably low cost. For example many of the "hot" surface IR emitters are associated with engine exhausts, AGE exhausts pipes and manifolds and support tools. Many of these can be simulated with Calrod hot plates of various sizes and power outputs.

After the initial field test program is completed a decision should be made as to what sources would be purchased and incorporated into the laboratory test fixture arrangement. These items would then be procured or borrowed as GFE from the Air Force. Some of these false alarm sources would be simulated by techniques developed in the qualification test facility and not be a direct result of field measurements at Air Force bases. Most work in the facility would be to develop test procedures and representative simulations.

The nature and properties of spectral emissions from the remaining sources would then be analyzed. Options for simulations would be developed and analyzed for practicality, cost and degree of duplication of radiation emissions. Simulation approaches would be selected and implemented.

The layout of the fixtures that would be required for the above discrete and complex sources would be determined and designed. The fixtures would most likely be mounted in a moving configuration that would provide for simultaneous multiple-source exposures to detectors at various angles and at various times-of-exposures. Tests would then be conducted to determine what configuration of sources and detectors would best represent the real geometry and other physical conditions in the field.

Fire detectors would be purchased from industry for use in the development of performance qualification test procedures. The manufacturers would be given the performance test results associated with their detectors and asked to provide comments and recommendations regarding false alarm immunity criteria and methods of conducting qualification test procedures.

Independent test procedures would then be developed for each test that would incorporate the above sources and simulations. These procedures would be carried-out a number of times to verify ease of duplication and verification of repeatable results. The optical measurement equipment used in the field tests and other laboratory test measurements would also be used to verify that detectors are exposed to the correct radiation wavelengths and intensities. The format of the test procedures would be similar to that used in most military standard component procurements where quality assurance is a major part of the qualification tests.

During the entire program the detector industry would be asked to review results and to make recommendations concerning experimental approach, test procedures, simulations and false alarm sources. The draft test procedures document would be provided to industry for their input. The recommended final draft copy would then be provided to the Air Force for approval and disposition.

After publication, the new Air Force Optical Fire Detector False Alarm Immunity Test Procedures Standard would be provided to industry, Air Force Base Fire and Civil Engineering Departments, Air Force fire protection organizations, and procurement organizations responsible for the purchase of fire protection systems for AF applications.

SECTION IV

MANAGEMENT AND ADMINISTRATIVE REQUIREMENTS

As stated in Section II, two areas of requirements must be satisfied to prove feasibility of successful completion of a Phase II effort. These areas include technical requirements and management and administrative requirements. The feasibility of satisfying the former technical requirements was demonstrated in the previous Section III. This Section addresses the management and administrative requirements.

A. ABILITY TO ACCOMPLISH PROGRAM OBJECTIVES ON SCHEDULE - ADMINISTRATIVE REQUIREMENT 1

To meet this administrative requirement the Air Force and the Phase II contractor should jointly establish schedules and approaches to meeting various objectives. The contractor can only propose schedules and milestones but the Air Force would be responsible for the actual scheduling, especially for the field measurements where requests for the use of aircraft, facilities and base personnel would have to be made weeks or months in advance. Also, scheduling and management procedures for the Phase II effort would have to follow current program management practices of the AF Systems Command for the program support outlined herein.

In summary, (1) a viable laboratory approach has been developed that is practical and easy to accomplish; (2) appropriate optical measurement and laboratory equipments have been identified and recommended; (3) the field measurements effort has been determined to be feasible as long as the proposed aircraft, facilities and other items can be made available by the AF in a reasonable time period; and (4) all inputs from the Air Force base and program personnel have been positive regarding the importance of this effort and their willingness to provide assistance during Phase II.

B. ARRANGEMENTS AND COORDINATION WITH AIR FORCE BASES - ADMINISTRATIVE REQUIREMENT 2

The mechanisms are in-place to maintain coordination between contractor, program office, AF Systems Command and respective AF base management. These mechanisms and interfaces do not have to be redefined for this program.

Aircraft are usually committed for missions some months in advance. Also, AFB facilities are used routinely for test programs and operational maintenance and support. The requirements of this program cannot be construed to dictate the availability of facilities and support services at any Air Force base. It is therefore of major importance that communications and understanding are established early in the program in order to minimize administrative problems.

The visits made to Air Force bases were beneficial in determining lines-of-command, interfaces and points of decision necessary to plan what must be accomplished in Phase II. A willingness to help was demonstrated at all bases visited. Every person contacted recognized the problems with false alarms and the need to solve the problem. Many AF personnel provided candid information on past false alarm problems and offered assistance during a Phase II effort.

No major obstacles in conducting a Phase II field measurements program were identified during the Phase I effort. Similar field measurements have been successfully conducted in the past.

As with any base support effort, it is important to specify in writing the nature of the on-base efforts, what is the purpose, who and what will be involved, the time period of on-base operations, who is responsible, and what base support is required. Such request messages would be sent through appropriate AF channels.

If for any reason the selected AFB and/or its equipment and facilities not be available within some predetermined time period for some or all the measurements discussed in Section III, the measurements could be conducted at other AF bases where fighter and large body aircraft are located and where AGE items and other possible false alarm sources exist. In other words, there are numerous options available to complete the field measurements phase of the program, although there could be cost and schedule impacts.

There do not appear to be any near-term options for B-2-associated measurements at any base other than Edwards. Whiteman AFB offers the only other possible option in the near future.

It is concluded that the Phase II/III goals of this SBIR program can be accomplished without any major unforeseen schedule impact according to the program intents of the AF, and that the AF has all the necessary administrative tools in existence to effectuate the entirety of the Phase II effort without major time delays or cost impacts.

SECTION V

CONCLUSIONS

Section II addressed the technical and administrative and management requirements that were deemed necessary to successfully define the nature and properties of radiation-emitting sources that may cause optical fire detectors to false alarm and/or activate the suppressant subsystem.

Sections III and IV discussed each of the requirements and provided insight as to the feasibility of accomplishing each and every requirement.

The following conclusions are the result of this Phase I effort.

1. The occurrence of false alarms and false activations of optical fire detector subsystems and extinguishing subsystems in aircraft hangars was validated in the Phase I study. At a minimum, such events have occurred at those AF bases listed in Section III-C and other locations listed by the Navy Safety Center. The older, single-band UV detectors that were installed a few years ago (and can still be purchased via the GSA Federal Supply Schedule as AF approved items) have a greater frequency-of-occurrence of false alarms than current UV/IR detectors and have been disconnected at some AF base locations. Regardless of how low or high is the frequency-of-occurrence of false alarms, the fact that they do occur and can result in financial loss and curtailment of AF missions was validated during this study.

Information provided by the manufacturers of current UV/IR detectors indicates that they are aware of about 20 recent events. Most of these events were caused by one or more intense lights/lamps, welding, heater elements, and AGE items. Other events were the result of environmental factors, reliability of components and inadequate maintenance/installation. Some specific examples included electronic component failures, water inside housings, corrosion, and mechanical failure due to vibration induced by aircraft engines.

2. Discussions with aircraft ground crews and maintenance personnel at AF bases indicated that there have been occasions when AGE items and intense lights produced sufficient levels of UV and IR to set-off an optical fire detector if one had existed in the facility. The occurrence of aircraft and AGE wet engine starts/backfires and small nacelle fires that were identified during this study would have also set-off optical fire detectors if they were present.

3. Several types of UV and IR emission sources can be present in and near hangars that may affect the performance of optical fire detectors. Most of the potential causes of false alarms/activations include those discrete and complex sources listed in Section III-C. Very few of these items are cited in current AF detector procurement performance specifications as possible false alarm sources to which detectors should be immune.

4. The presence of false alarm sources and fire threats are more predominant in some hangar operations than in others. Many AGE items used in CONUS operations remain outside the hangars while in USAFE operations these same AGE items, as well as most other aircraft-related items, are typically inside the shelter unit. The simultaneous presence then of all of these potential false alarm sources, including running engines, portends a higher probability of both fire events and false alarms of the fire protection systems. A possible reason that few if any false alarm events have been reported for USAFE hardened shelters is that very few have optical fire detection systems installed. UV single-band detectors that are installed in a some PACAF base shelters have false alarmed in the past and have been disconnected in some cases.

A conclusion of this study is that the potential for false alarms is much higher than is reflected by the number of past reported events, especially for those shelter/hangar units that operate fighter aircraft in PACAF and USAFE locations.

5. The current UV/IR detectors being supplied by industry perform according to the specifications to which they are procured. They can false alarm if they are not designed to be immune to <u>all</u> the potential false alarm sources that they may be exposed to during their lifetimes. Characterization of the nature and properties of all potential false alarm sources would provide more stringent specifications to increase detector immunity and reliability.

It is also concluded that more stringent specifications of environmental factors/extremes, greater reliability/MTBF requirements and follow-up inspection and testing of installations may help to reduce the number of false alarms/failures caused by these items. About half of the false alarms and false dumps identified were due to these factors.

6. It was concluded from this study that rate-of-rise thermal/heat detectors have been involved in false alarms and dumps at several bases. These detectors are sensitive to engine starts in a hangar where the engine blast/effluent is so hot that the rate-of-rise of temperature registered by the detectors on the ceiling exceed the design temperature rate requirement. Most of these problems were due to installations that were not high enough above the floor or that the selected detectors had too low of a heat/rate-of-rise temperature setting. Approximately 10 events of this type occurred in the past year at one California AFB which resulted in the loss of over 1500 gallons of AFFF and depleted the supply. Another 20 or so events also occurred but were curtailed manually before suppressant was dumped. These events were all due to the engine emissions at start-up of high performance aircraft. The fire detection systems were turned-off awaiting appropriate replacements and better installations.

7. Edwards AFB has the largest contingency of aircraft and false alarm source potentials, including AGE items, than any other air base surveyed. It also houses the B-2 aircraft and has hush houses, engine test stands and NDI facilities needed during a Phase II effort.

8. Most of the simple/discrete and some complex sources can be purchased and integrated into the qualification test laboratory fixtures. Quartz halogen lamps, high pressure sodium lamps, mercury vapor lamps, multivapor lamps, fluorescent lamps, electronic photo flash lamps, flashlights, vehicle lights, strobe lamps, movie lamps, quartz lamps, sodium vapor lamps, xenon lamps, heating elements, acetylene welder, electric arc, matches, lighters, and solar spectrum simulators are some examples. No problems were identified regarding the preparation of false alarm arrays and test fixtures.

9. Optical measurement and data recording equipments that cover the UV and IR regions of interest are readily available. Both hand-held low-resolution and table mounted high-resolution pyrometers/spectrometers are needed for the field measurements and qualification test procedures parts of a Phase II effort.

10. The methodology and experimental procedures are routine and have been determined for the field measurements part of the program. There are several options available in conducting the field measurements at different times and in different locations, thus,minimizing scheduling/conflict constraints.

11. The qualification test procedures facility can be easily outfitted with available standard electronic and mechanical tools and support items. There are no problems associated with the establishment of such a facility. It is concluded that this facility should be located in the general geographical region where most of the field measurements would take place.

12. The Air Force has in-place all the necessary management interfaces and procedures to schedule the Phase II effort and to assure that the goals of the SBIR effort are met. There was strong support on the part of all AF representatives contacted during this Phase I effort to provide assistance in solving the optical fire detector false alarm problem.

13. This Phase I effort has proven the importance of determining the characteristics of potential false alarm sources and in establishing qualification test procedures to prove detector immunity. The feasibility of successfully conducting the Phase II effort and satisfying the goals of this SBIR program has been established.

14. A final conclusion is that the conduct of a Phase II effort would result in cost benefits to the government and would also provide greater assurance for aircraft mission implementation, success and survivability.

SECTION VI

RECOMMENDATIONS

As a result of this Phase I SBIR contract, the following recommendations can be made and supported:

1. The Air Force should specify in its purchase descriptions detailed requirements for optical fire detectors and detection subsystems. These requirements should include immunity to false alarm sources, performance reliability in environments (temperature, shock, vibration, water immersion, salt, humidity and explosive atmosphere), lifetime, and methods of installation.

2. The Air Force should determine the nature and properties of the false alarm sources to which fire detectors and fire detection subsystems would be exposed and specify these characteristics to industry.

3. In addition to the specification of false alarm characteristics, test procedures and test simulation approaches should be stipulated in the procurement proposal requests (or purchase descriptions) that industry would be required to satisfy in order to verify detector and/or detection system performance conformity to specifications.

4. In the defining/measuring the characteristics of false alarm sources, all Air Force applications should be taken into account, including various types of hangars for many different aircraft, maintenance facilities, hot pits, hush houses and any other facilities that require the use of optical fire detection.

5. In addition to the qualification test procedures that should be followed in proving detector immunity to false alarm sources, design and other test requirements should be imposed to increase the performance of such devices in the environments they are exposed to. As shown herein, many of the false alarm events have been due to environmental factors such as shock, vibration water immersion/leakage, corrosion of components, and short lifetimes/low MTBFs.

At a minimum, consideration should be given to imposing the following military standards in the specifications of purchases of near-future optical fire detectors: Mil-Std-810D (environmental performance) sections 501.1 (high temperature), 502.2 (low temperature), 512.2 (leakage, water immersion), 511.2 (explosive atmosphere), 516.3 (shock), 514.3 (vibration), 507.2 (humidity), 500.2 (altitude), and 509.2 (salt); Mil-Std-461C (electromagnetic emission and susceptibility; category A1c, aerospace ground equipment associated with aircraft and electronic support equipment), sections CE03, CE07, CS02, CS06, RE02, RS02 and RS03; and Mil-Std-462H (EMI measurements) to conduct the latter qualification test measurements.

Satisfaction of the above military standards would reduce the probability of false alarms or failures due to environmental factors and electromagnetic emissions. These standards represent only a few of those deemed necessary for the HAS Fire Protection System (References 3 and 6). Also, the

AF should review the level of reliability and MTBF, if any, that should be imposed on optical fire detectors, controllers and fire protection systems in general. Such requirements do not presently exist.

7. The purchase description that results from a Phase II effort should encompass false alarm immunity requirements, test procedures approach and the environmental specifications stated in 6 above.

8. During the course of the Phase II effort industry should be kept closely informed and asked for their recommendations and comments as the program progresses. This would help industry in their efforts to meet the Air Force's requirements in a timely manner.

9. The procurement approach utilized in current acquisitions of optical fire detectors and logic electronic controllers should be reviewed by the AF in terms of: (a) "component approach" vs. "systems approach", (b) performance and qualification test specifications, and (c) use of commercial testing organizations for certifications vs. internal industrial and other certified laboratory testing according to military standards. The HAS Program Purchase Description should also be reviewed in this context because that detection subsystem was developed to meet the major fire threats and major false alarm potentials that may be experienced in operational shelter units. The issue here is to what degree should future fire detectors and electronics be designed and qualified to military vs. commercial standards.

10. Edwards AFB should be selected as the location for the field measurements. The qualification test procedures facility should be located in the southern California region near Edwards AFB.

11. The problems identified in the Phase I effort with false alarm sources exemplifies the need to proceed in developing more appropriate and thorough design and performance specifications for optical fire detectors. It is recommended that a Phase II effort be pursued with diligence by the USAF and that it be given high priority because of the potential financial benefits to the AF and the benefits of increased aircraft mission success and survivability.

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